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AGRICULTURAL METEOROLOGY: SEASONAL INCIDENCE OF RAINLESS AND RAINY PERIODS AT WINNIPEG, SWIFT CURRENT, AND EDMONTON[1]

BY J. W. HOPKINS[2]

Abstract

The frequency of sequences of consecutive days without rain and with rain at each of the above-named meteorological stations has been determined from their records of daily precipitation for the months April to September of the years 1916 to 1937. It is inferred from these frequencies that rainy or rainless days do not in general occur entirely at random, but that the same kind of weather tends to persist over successive days. The statistics have also been used to estimate the expectation of rainless periods. At all three stations, this is least in midsummer (June and July) and greatest in spring and autumn.

Introduction

In a recent Technical Bulletin of the United States Department of Agriculture, Blumenstock (1) points out that lengthy rainless intervals are an important factor in the initiation of soil erosion by wind action, and that it is therefore desirable to ascertain how periods without precipitation vary in length from place to place and from season to season of the year, in order to arrive at drought-expectancy figures from which this particular climatic risk may be evaluated. The writer has extracted from the published records of the Meteorological Service of Canada (3) statistics of the daily occurrence of rains during the summer period April 1 to September 30 of the 22 years, 1916–1937, at three representative meteorological stations in the Prairie Provinces of Canada; these are presented and discussed in the following sections of this paper. The three stations selected for this purpose were Winnipeg, Manitoba (lat. 49° 53′ N., long. 97° 7′ W., alt. 760 ft.), Swift Current, Saskatchewan (50° 20′ N., 107° 45′ W., 2440 ft.), and Edmonton, Alberta (53° 33′ N., 113° 30′ W., 2158 ft.)

Data

Table I shows the total number of days, during the six months of each year considered, on which no measurable amount of precipitation (i.e., less than 0.01 in. of rain) was recorded. As has been noted elsewhere (6) the number of rainless days is on the average least during midsummer, but the seasonal trend in this respect is less than proportional to the marked trend in the actual amounts of rain received.

[1] *Manuscript received April 25, 1941.*

Contribution from the Division of Biology and Agriculture, National Research Laboratories, Ottawa, Canada. Published as Paper No. 184 of the Associate Committee on Grain Research, and as N.R.C. No. 1004.

[2] *Statistician, National Research Laboratories, Ottawa.*

TABLE I

NUMBER OF RAINLESS DAYS PER MONTH, 1916–1937, AT WINNIPEG, SWIFT CURRENT, AND EDMONTON

Year	Apr.	May	June	July	Aug.	Sept.
			Winnipeg			
1916	25	18	18	25	22	20
1917	25	30	18	21	20	22
1918	24	24	18	20	18	20
1919	25	24	23	24	21	18
1920	23	25	20	25	22	19
1921	22	22	20	21	21	16
1922	22	19	20	22	24	20
1923	24	24	25	15	23	20
1924	14	26	21	22	20	21
1925	20	24	11	22	16	24
1926	25	21	19	26	19	16
1927	19	18	16	20	22	19
1928	21	26	17	17	17	24
1929	25	23	20	23	26	25
1930	24	15	19	22	22	23
1931	25	24	22	15	23	18
1932	21	27	19	19	23	23
1933	22	27	22	17	21	20
1934	22	22	16	21	22	15
1935	19	25	16	22	19	16
1936	21	23	21	24	29	25
1937	17	21	19	22	20	18
Mean	22.0	23.1	17.2	21.2	21.4	20.1
Standard deviation	2.9	3.5	2.9	3.0	2.9	3.0
χ^2	30.952	42.749**	24.519	28.440	26.062	28.906
			Swift Current			
1916	25	15	15	20	22	22
1917	19	29	21	25	22	23
1918	24	24	23	21	20	27
1919	23	25	26	27	23	23
1920	20	22	17	24	26	24
1921	24	20	20	19	23	21
1922	22	18	18	22	22	25
1923	22	23	14	14	23	29
1924	24	25	14	21	17	24
1925	17	26	20	23	22	19
1926	24	19	17	24	20	22
1927	18	11	20	16	25	21
1928	23	26	12	19	21	28
1929	21	24	23	25	27	21
1930	21	25	21	22	22	22
1931	24	26	20	23	25	22
1932	19	24	16	21	20	24
1933	22	24	20	27	22	21
1934	26	19	11	23	25	17
1935	18	23	14	19	25	28
1936	24	24	16	25	26	26
1937	25	21	24	22	24	22
Mean	22.0	22.4	18.3	21.9	22.8	23.2
Standard deviation	2.6	4.1	4.0	3.2	2.4	3.0
χ^2	24.110	56.575**	45.842**	34.520*	20.470	36.202*

TABLE I—*Concluded*

NUMBER OF RAINLESS DAYS PER MONTH, 1916–1937, AT WINNIPEG, SWIFT CURRENT, AND EDMONTON—*Concluded*

Year	Apr.	May	June	July	Aug.	Sept.
			Edmonton			
1916	24	16	21	18	20	19
1917	21	21	18	18	15	23
1918	23	17	14	18	9	25
1919	22	23	22	16	20	18
1920	18	18	16	23	24	24
1921	25	21	17	16	19	23
1922	24	24	19	18	17	25
1923	26	21	16	15	15	24
1924	20	25	17	14	15	25
1925	22	24	17	21	16	20
1926	25	22	18	26	16	15
1927	27	20	17	14	23	15
1928	15	26	12	18	15	27
1929	16	22	21	18	18	24
1930	23	21	10	22	19	17
1931	28	22	15	15	18	14
1932	18	26	19	16	25	23
1933	20	19	14	11	23	16
1934	25	20	11	20	18	12
1935	25	22	11	18	14	22
1936	22	20	15	19	19	21
1937	21	21	16	11	16	21
Mean	22.3	21.4	16.2	17.5	17.9	20.6
Standard deviation	3.4	2.6	3.3	3.6	3.7	4.2
χ^2	43.289**	21.939	30.492	35.890*	38.586*	58.429**

* *Exceeds 5% point (32.671).*
** *Exceeds 1% point (38.932).*

Tables II, III, and IV give the frequency of occurrence, at each station, of rainless periods of varying length, following each rainy day, during the 22 years, and Table V gives similar information in respect of sequences of rainy days following each dry day. It requires to be noted that whereas the frequencies listed in Table I are based strictly on calendar months, some elasticity of definition had to be introduced in order to avoid the arbitrary truncation in Tables II to V of natural periods, either wet or dry, overlapping from one month into the next. Accordingly, if a natural sequence of 15 rainless days, for example, began on June 20, so that 11 of the days involved fell in June and four in July, the entire sequence of 15 would be credited to the month of June. On the other hand, had the date of commencement been June 25, so that the major part of the sequence actually occurred in July, the entire sequence would have been credited to the latter month. It may be anticipated that additions to and subtractions from the records for each month occasioned in this way will approximately balance.

TABLE II

FREQUENCY OF OCCURRENCE OF RAINLESS PERIODS OF SPECIFIED LENGTH, WINNIPEG, 1916–1937

Rainless period, days	Apr.		May		June		July		Aug.		Sept.	
	Observed	Random exp.	Observed	Random exp.	Observed	Random exp.	Observed	Random exp.	Observed	Random exp.	Observed	Random exp.
0	61	44.3	68	48.0	96	103.0	72	70.0	82	64.7	93	73.3
1	28	32.5	33	35.7	58	59.2	48	47.7	34	44.6	40	49.1
2	18	23.9	23	26.6	36	34.0	23	32.5	24	30.7	26	32.9
3	9	17.6	13	19.8	20	19.5	22	22.2	25	21.2	16	22.0
4	11	12.9	12	14.8	9	11.2	24	15.1	11	14.6	18	14.8
5	8	9.5	8	11.0	5	6.4	13	10.3	12	10.0	10	9.9
6	7	7.0	8	8.2	6	3.7	5	7.0	6	6.9	6	6.6
7	4	5.1	4	6.1	0	2.1	4	4.8	0	4.8	4	4.4
8	4	3.8	1	4.6	3	1.2	3	3.3	3	3.3	0	3.0
9	5	2.8	2	3.4	5	0.7	3	2.2	3	2.3	2	2.0
10	1	2.0	3	2.5	3	0.4	1	1.5	2	1.6	1	1.3
11	2	1.5	3	1.9	0	0.2	1	1.0	0	1.1	1	0.9
12	3	1.1	3	1.4	0	0.1	0	0.7	0	0.7	0	0.6
13	2	0.8	1	1.0	0	0.1	1	0.5	0	0.5	1	0.4
14	1	0.6	1	0.8	1	0.04			2	0.4	0	0.3
15	1	0.4	1	0.6					1	0.2	0	0.2
16	0	0.3	3	0.4					1	0.2	1	0.1
17	0	0.2	0	0.3					0	0.1	0	0.1
18	0	0.2	0	0.2					2	0.1	1	0.05
19	2	0.1	0	0.2							1	0.04
20			0	0.1							0	0.02
21			0	0.1							0	0.02
22			0	0.1							0	0.01
23			0	0.05							0	0.01
24			0	0.04							0	0.01
25			0	0.03							1	0.003
26			0	0.02								
27			0	0.02								
28			0	0.01								
29			0	0.01								
30			0	0.01								
31			0	0.01								
32			1	0.004								
χ^2	17.403*		20.481*		11.848		9.513		15.910*		13.754	

* *Exceeds 5% point.*

Length and Frequency of Recorded Sequences

In the bulletin to which reference has already been made, Blumenstock (1) is of the opinion that there is a linear relation between the length of a rainless period and the logarithm of the frequency of its occurrence. It is of interest to note that, for this to be so, the probability of rain occurring on any particular day must be statistically independent of the weather of the preceding day or days. In this event, let p be the probability of a day being rainy, and q $(= 1 - p)$ the complementary probability of its being rainless. Then if rain occurs on any specified day, the probability that the next day will also be rainy is p. On the other hand the probability that the next day will be fine, but that rain will occur again on the second next day, will be qp; and in

TABLE III

FREQUENCY OF OCCURRENCE OF RAINLESS PERIODS OF SPECIFIED LENGTH, SWIFT CURRENT, 1916–1937

Rainless period, days	Apr.		May		June		July		Aug.		Sept.	
	Observed	Random exp.	Observed	Random exp.	Observed	Random exp.	Observed	Random exp.	Observed	Random exp.	Observed	Random exp.
0	79	46.1	96	55.1	133	99.3	77	58.7	72	46.7	48	33.2
1	21	33.9	24	39.9	35	60.5	29	41.5	23	34.4	27	25.7
2	13	24.9	17	28.8	31	36.8	27	29.3	10	25.3	13	19.9
3	7	18.3	19	20.8	15	22.4	11	20.7	20	18.6	13	15.4
4	15	13.4	5	15.1	10	13.7	15	14.6	8	13.7	5	11.9
5	9	9.9	7	10.9	10	8.3	9	10.3	14	10.1	6	9.2
6	4	7.3	6	7.9	6	5.1	8	7.3	8	7.4	6	7.2
7	3	5.3	7	5.7	3	3.1	13	5.2	7	5.5	3	5.5
8	5	3.9	3	4.1	7	1.9	5	3.6	2	4.0	5	4.3
9	2	2.9	3	3.0	1	1.2	3	2.6	3	3.0	1	3.3
10	1	2.1	1	2.2	2	0.7	1	1.8	2	2.2	2	2.6
11	3	1.6	1	1.6	0	0.4	0	1.3	2	1.6	5	2.0
12	2	1.1	0	1.1	0	0.3	0	0.9	0	1.2	2	1.5
13	5	0.8	3	0.8	0	0.2	0	0.6	3	0.9	0	1.2
14	1	0.6	1	0.6	0	0.1	0	0.4	0	0.6	1	0.9
15	4	0.4	0	0.4	0	0.1	0	0.3	0	0.5	1	0.7
16			2	0.3	0	0.04	0	0.2	1	0.4	2	0.6
17			1	0.2	1	0.02	0	0.2	0	0.3	1	0.4
18			1	0.2			0	0.1	0	0.2	0	0.3
19			1	0.1			0	0.1	1	0.1	2	0.3
20			0	0.1			0	0.1	0	0.1	0	0.2
21			0	0.1			2	0.04	0	0.1	1	0.2
22			1	0.04					0	0.1	0	0.1
23									0	0.04	1	0.1
24									1	0.03	0	0.1
25											0	0.1
26											0	0.04
27											0	0.03
28											0	0.03
29											1	0.02
30											0	0.02
31											0	0.01
32											0	0.01
33											0	0.01
34											0	0.01
35											1	0.004
χ^2	63.076**		53.106**		31.428**		28.191**		32.066**		23.467**	

** *Exceeds 1% point.*

general the probability of a sequence of 0, 1, 2, . . . n rainless days, terminated by rain on the 1st, 2nd, 3rd, . . . $n + 1$th days will be given by successive terms of the geometric series

$$p, qp, q^2p, \ldots q^np$$

(2, 4) from which the logarithm of the probability of a sequence of exactly n dry days is

$$\log p + n \log q,$$

a linear function of n as postulated.

A further requirement for linearity in the case of observations extending over a period of years is that p must remain constant throughout. If this

TABLE IV

FREQUENCY OF OCCURRENCE OF RAINLESS PERIODS OF SPECIFIED LENGTH, EDMONTON, 1916–1937

Rainless period, days	Apr.		May		June		July		Aug.		Sept.	
	Observed	Random exp.	Observed	Random exp.	Observed	Random exp.	Observed	Random exp.	Observed	Random exp.	Observed	Random exp.
0	76	44.8	105	68.4	166	137.7	163	133.3	139	117.8	97	61.8
1	25	33.3	29	47.2	50	74.3	56	75.2	54	68.1	20	42.4
2	15	24.7	25	32.6	36	40.1	29	42.5	26	39.3	25	29.1
3	13	18.3	14	22.5	15	21.6	18	24.0	23	22.7	11	20.0
4	7	13.6	9	15.6	15	11.7	12	13.5	13	13.1	9	13.7
5	6	10.1	11	10.7	7	6.3	11	7.6	6	7.6	12	9.4
6	9	7.5	6	7.4	5	3.4	3	4.3	8	4.4	5	6.5
7	5	5.6	6	5.1	0	1.8	8	2.4	6	2.5	2	4.4
8	3	4.1	3	3.5	1	1.0	2	1.4	2	1.5	4	3.0
9	2	3.1	3	2.4	1	0.5	3	0.8	0	0.8	2	2.1
10	1	2.3	3	1.7	1	0.3	0	0.4	2	0.5	3	1.4
11	4	1.7	1	1.2	1	0.2	1	0.2			0	1.0
12	1	1.3	1	0.8	0	0.1					1	0.7
13	3	0.9	0	0.6	1	0.05					2	0.5
14	0	0.7	2	0.4							1	0.3
15	1	0.5	0	0.3							0	0.2
16	0	0.4	0	0.2							1	0.2
17	1	0.3	0	0.1							0	0.1
18	1	0.2	2	0.1							1	0.1
19	0	0.2	1	0.1							0	0.05
20	0	0.1									0	0.04
21	0	0.1									0	0.02
22	0	0.1									0	0.02
23	0	0.05									0	0.01
24	0	0.04									0	0.01
25	1	0.03									1	0.01
χ^2	37.223**		38.493**		18.163**		23.459**		18.679**		43.515**	

** *Exceeds 1% point.*

is not so, and p fluctuates from year to year, the relative frequency of sequences of 0, 1, 2, 3, etc. rainless days during the period as a whole will constitute a series which is compounded of a number of separate geometric series, but which is not itself geometric.

A priori, it might perhaps be considered unlikely that the meteorological conditions prevailing in the Prairie Provinces would satisfy either of the foregoing requirements. A major part of the precipitation in this area is associated with the passage of low pressure areas of such an extent that the weather of successive days might be affected by the same "low", and hence could hardly be regarded as statistically independent. Furthermore, there is generally some secular variation in the rainfall recorded at any point over a period of years, alternating periods of above- and below-average precipitation, which might be expected to affect the value of p, tending to occur at irregular intervals (6).

Judging from the observations recorded in Tables I to IV, it would seem that both of these factors are in practice operative. Thus in order to test

TABLE V

FREQUENCY OF OCCURRENCE OF SEQUENCES OF DAYS WITH RAIN, WINNIPEG, SWIFT CURRENT, AND EDMONTON, 1916–1937

Number of consecutive days with rain	Apr.		May		June		July		Aug.		Sept.	
	Observed	Random exp.	Observed	Random exp.	Observed	Random exp.	Observed	Random exp.	Observed	Random exp.	Observed	Random exp.
Winnipeg:												
0	376	355.6	407	388.1	254	232.6	310	313.0	332	317.0	327	307.4
1	62	94.3	73	99.0	97	99.0	97	99.6	73	98.6	73	101.5
2	33	25.0	24	25.3	30	42.2	41	31.7	33	30.6	40	33.5
3	6	6.6	12	6.4	11	18.0	5	10.0	18	9.5	12	11.1
4	6	1.8	4	1.6	9	7.6	3	3.2	3	3.0	2	3.7
5	0	0.5	2	0.4	3	3.2	3	1.0	1	0.9	3	1.2
6	1	0.1			1	1.4					1	0.4
7											1	0.1
Swift Current:												
0	386	357.1	385	353.5	274	241.2	356	335.0	378	360.0	461	428.1
1	55	94.7	53	98.0	55	94.3	66	98.2	59	95.0	58	96.7
2	28	25.1	28	27.1	35	36.9	33	28.8	39	25.1	25	21.8
3	9	6.7	15	7.5	16	14.4	14	8.4	11	6.6	4	4.9
4	2	1.8	2	2.1	8	5.6	5	2.5	1	1.8	5	1.1
5	5	0.5	1	0.6	4	2.2			0	0.5		
6	0	0.1	3	0.2	1	0.9			0	0.1		
7	0	0.03	1	0.04	1	0.3			0	0.03		
8	1	0.01	1	0.01	1	0.1			0	0.01		
9					1	0.05			1	0.002		
Edmonton:												
0	365	341.5	360	328.0	210	189.9	258	225.2	245	221.3	322	291.7
1	49	88.0	62	101.5	60	87.4	65	98.1	62	93.4	43	91.5
2	31	22.7	27	31.4	40	40.3	33	42.7	40	39.5	36	28.7
3	6	5.8	10	9.7	18	18.6	22	18.6	19	16.7	18	9.0
4	5	1.5	11	3.0	11	8.6	12	8.1	11	7.0	3	2.8
5	2	0.4	1	0.9	9	3.9	4	3.5	3	3.0	1	0.9
6	2	0.1	3	0.3	3	1.8	1	1.5	2	1.2	1	0.3
7			1	0.1	1	0.8	2	0.7	1	0.5	0	0.1
8							2	0.3			1	0.03

the constancy of q, and hence also of $p = 1 - q$, the index of dispersion χ^2 appropriate to a binomial distribution was calculated (following the procedure of Fisher (5)) from the annual variation in the number of rainless days recorded in each month at the three stations; it is shown at the foot of the corresponding column in Table I. Of the aggregate 18 values of χ^2 computed in this way, nine exceed the 5% and five exceed the 1% point, a circumstance that is hardly compatible with the assumption that for any specified month and station, e.g., April at Edmonton, p and q are in fact the same from year to year.

The frequency distributions of sequences of rainless days given in Tables II to IV are also for the most part inconsistent with the expected relative frequencies (listed in the columns headed "random expectation") calculated from the

geometric series on the assumption, as indicated above, that for any specified month and station, the average values of p and q obtained from Table I are applicable to every day covered by the period of record. It is very evident that at both Swift Current (Table III) and Edmonton (Table IV) there was, in all the six months considered, on the one hand an excess of occasions on which a rainy day was immediately followed by another rainy day (shown as sequences of zero dry days) and of dry sequences of six or more days, and on the other a deficiency of rainless periods of one to three days' duration. The statistical significance of these deviations of observation from hypothesis was tested by the calculation of χ^2 in the usual way (5),the terminal frequencies in each case being grouped so as to provide a minimum expectation of five. All 12 of the resulting values of χ^2 for these two stations are in excess of the 1% point.

Similar tendencies are to be noted in the records for Winnipeg (Table II), but here the deviation of the observed frequencies from the random expectation is less marked, and only three of the six values of χ^2 are individually statistically significant. An alternative test, due to Cochran (4), which does not take into consideration the number of "zero sequences" but which involves no grouping of the tail frequencies and consequent loss of information as in the χ^2 test was accordingly applied to these series. It was thus found that the occurrence of lengthy rainless periods in June at this station was also significantly in excess of the random expectation.

The observations as a whole are clearly inconsistent with the purely random occurrence of either rainless or rainy spells (the two being of necessity complementary), but are indicative of a tendency of the prevailing weather to persist over several days, especially at the two more westerly stations. Figs. 1 and 2 illustrate the effect of this on the frequency distribution of rainless and rainy sequences. The deviation from linearity in the relation between length of period and logarithmic frequency is apparent although, owing to the rarity of the lengthier sequences, the tails of the distributions are determined with uncertainty. These accordingly did not seem to merit any more extensive treatment than graduation by the second-degree curves shown, which were fitted by the method of Least Squares.

A readily recognizable climatic characteristic arises from the proportion of occasions on which there is no change in the weather from one day to the next, i.e., on which a rainy day is followed by another rainy day, or a fine day by a second fine day. This proportion may be computed from Tables II to V. Table II, for example, comprises a total of 1247 days with rain, constituting the starting points defining the sequences of dry days recorded at Winnipeg. Of these, 472, giving rise to the tabulated "zero" sequences, were succeeded by another rainy day. Similarly Table V comprises a total of 2788 rainless days at Winnipeg, providing the reference points for the observed sequences

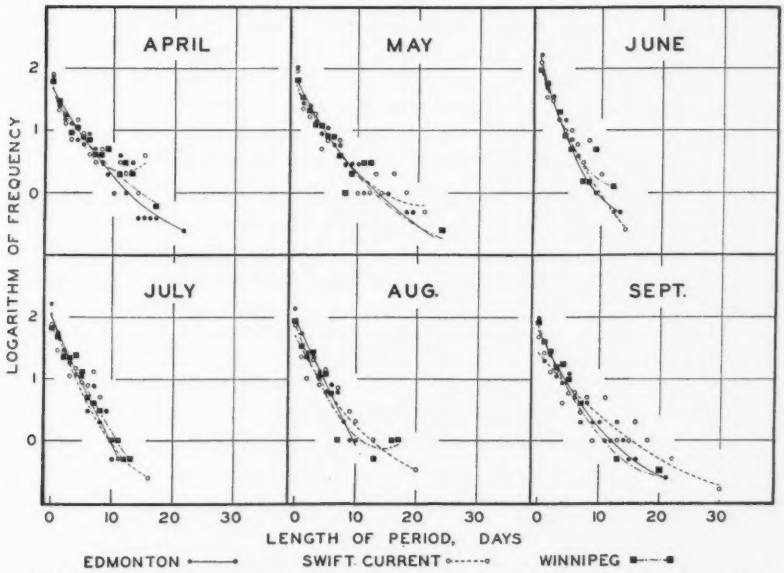

FIG. 1. *Logarithmic frequency (1916–1937), by months, of rainless periods of specified length at Winnipeg, Swift Current, and Edmonton.*

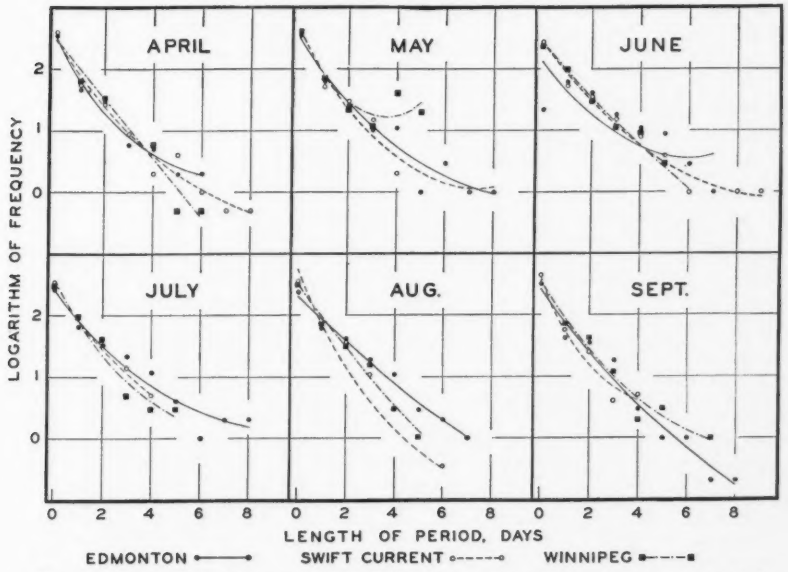

FIG. 2. *Logarithmic frequency (1916–1937), by months, of rainy periods of specified length at Winnipeg, Swift Current, and Edmonton.*

of rainy days, of which 2006 were followed by another rainless day. Of the total of 4035 days considered therefore, 2478 or 61% were followed by another rainy or rainless day as the case might be. The corresponding percentages for Swift Current and Edmonton are 68 and 63, respectively.

Expectation of Rainless and Rainy Periods

Tables II to IV, each summarizing the experience of 22 years, may be used to make estimates of drought expectancy; the results are shown in Table VI. This last table indicates the length of rainless periods that must be expected on the basis of the (ungraduated) past experience cited to be attained or exceeded once per annum, once in five years, and once in 10 years during the specified month at each station. As the 10-year points are of necessity deduced from only two observed occurrences, they must be regarded as rough

TABLE VI

LENGTH OF RAINLESS PERIODS HAVING SPECIFIED EXPECTED FREQUENCIES

Station	Expected frequency	Length of period, days					
		Apr.	May	June	July	Aug.	Sept.
Winnipeg	Once per year	7	7	5	5	5	5
	Once in 5 years	13	14	9	9	14	11
	Once in 10 years	19	16	10	10	16	18
Swift Current	Once per year	8	7	5	7	7	8
	Once in 5 years	13	16	8	9	13	19
	Once in 10 years	15	18	10	10	16	23
Edmonton	Once per year	7	6	4	5	5	6
	Once in 5 years	13	12	6	8	7	13
	Once in 10 years	17	18	10	9	8	16

TABLE VII

EXPECTED FREQUENCY OF OCCURRENCE OF RAINY PERIODS OF SPECIFIED LENGTH

Station	Length of period, days	Expected frequency of occurrence, once in:					
		Apr.	May	June	July	Aug.	Sept.
Winnipeg	4 or more	3.1 yr.	3.7 yr.	1.7 yr.	3.7 yr.	5.5 yr.	3.1 yr.
	5 or more	22	11	5.5	7.3	22	4.4
	6 or more	22	> 22	22	> 22	> 22	11
Swift Current	4 or more	2.8	2.8	1.4	4.4	11	4.4
	5 or more	4.4	3.7	2.8	> 22	22	> 22
	6 or more	22	4.4	5.5	> 22	22	> 22
Edmonton	4 or more	2.4	1.4	0.9	1.0	1.3	3.7
	5 or more	5.5	4.4	1.7	2.4	3.7	7.3
	6 or more	11	5.5	5.5	4.4	7.3	11

approximations only. On this basis the expectation of rainless periods is least in midsummer (June and July) and greatest in spring and autumn. At Swift Current, for example, it may be anticipated that there will be at least five consecutive June days without rain each year; that eight or more consecutive rainless days during this month may be expected on the average once in five years; and 10 or more once in 10 years on the average. For the month of September on the other hand the corresponding minimum expectations at this station are 8, 19, and 23 days, respectively.

Unduly prolonged rainy periods may also be agriculturally disadvantageous, not only by hindering field work but also in some cases by facilitating or aggravating water erosion of soil (7). It is of course true that under prairie weather conditions the maximum duration of rainy periods recorded is much less than that of rainless ones. Nevertheless, the average frequencies deduced from Table V and recorded in Table VII indicate an appreciable incidence of sequences of as many as five or more consecutive days with measurable amounts of rain, particularly at Swift Current and Edmonton.

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VARIETAL DIFFERENCES IN BARLEYS AND MALTS

XII. SUMMARY OF CORRELATIONS BETWEEN 18 MAJOR BARLEY, MALT, AND MALTING PROPERTIES[1]

By J. A. Anderson[2], H. R. Sallans[3], and W. O. S. Meredith[4]

Abstract

A summary is presented of correlation studies based on data, for 11 barley properties and 7 malt properties, obtained by analysis of samples of 12 varieties of barley (and of the malts made from them) grown at 12 experimental stations in Canada. Intra- and intervarietal associations between pairs of properties were studied separately using means over all varieties for each station, and means over all stations for each variety. Simple correlation coefficients for all possible pairs of properties are reported. In addition, intravarietal partial correlation coefficients, independent of total nitrogen, and intervarietal partial correlation coefficients, independent of salt-soluble nitrogen, are also given.

The main purpose of the paper is to put on record, for ready reference, tables of statistics that may be useful to other investigators who are interested in the associations that exist between barley and malt properties, and the light that these throw on the nature of malting quality in barley.

Previous papers in this series (1, 2, 7-9, 16, 17, 19-22) presented the results of studies of the effects of variety and environment on a relatively large number of barley and malt properties. The data furnished conclusive proof that both factors have a significant effect on all the properties measured. It was also possible to examine, by means of correlation studies, certain of the associations that exist between various barley and malt properties, and thus to show that the inter- and intravarietal associations differ materially for many of the pairs of properties examined. It appears that these studies throw some light on the nature of malting quality in barley, a problem that is by no means solved and that will probably continue to attract the attention of malting chemists for many years. Accordingly it seemed useful to put on record in the present paper a brief summary of the results of the correlation studies made during the course of the investigations. A number of these have already been reported. The list is now completed and consists of inter- and intravarietal correlation coefficients for all possible pairs obtainable from 11 barley properties and 7 malt properties. To these have been added the corresponding intervarietal partial correlation coefficients, independent of salt-

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soluble barley nitrogen and the intravarietal partial correlation coefficients independent of total barley nitrogen.

The discussion of these correlation coefficients is not extensive. The main purpose is to put on record, for ready reference, tables of statistics that may be useful to other investigators interested in the same field of research.

Correlation Coefficients

In considering the correlation coefficients in the following sections, the reader should bear in mind that all determinations were made on the same set of 144 barleys and their corresponding malts and that these samples represented 12 varieties of barley grown at 12 widely separated experimental stations (1). The barleys were pure strain varieties grown on replicated randomized plots and the maltings were made in duplicate under carefully controlled and standardized malting conditions (1). Although the number of stations and varieties appears somewhat limited, the wide range in barley types (five, rough-awned six-rowed; four, smooth-awned six-rowed; and three, rough-awned two-rowed, varieties) and the range of 1.5 to 2.8% in the mean nitrogen content for stations suggests that the investigations covered a sufficiently wide range to yield useful estimates of the correlation coefficients.

It might be assumed that the relations reported would apply only under malting conditions that approximate very closely those employed for these investigations. However, studies on the effects of different malting treatments on malt quality (3–6, 18) indicate that when the same set of barleys is malted under quite widely varying conditions the varieties and stations are placed in essentially the same relative order within each treatment. Thus if a different system of malting had been employed in the investigations, it seems altogether probable that correlation coefficients thus obtained would not have differed markedly from those reported. Consequently, it appears that the present study serves to indicate relations that are inherent in barleys and in the malts produced from them by any reasonable and uniform malting procedure.

Obviously the results obtained in the present investigations could not be duplicated with pairs of barley and malt samples selected at random from commercial malt houses. With such a series of samples it would be impossible to separate the effects of variety (i.e., genetic constitution) from the effects of environment on the various barley and malt properties, nor would it be possible to study separately the intravarietal (i.e., interstation) and the intervarietal associations between pairs of properties. Moreover, the investigation would be further complicated by such differences as existed between the malting methods used in different malt houses.

Since the intra- and intervarietal associations between barley and malt properties differ widely, these are discussed separately in the following subsections.

TABLE I

SIMPLE INTRAVARIETAL CORRELATION COEFFICIENTS AND CORRESPONDING PARTIAL CORRELATION COEFFICIENTS, INDEPENDENT OF TOTAL NITROGEN, FOR BARLEY AND MALT PROPERTIES

Simple correlation coefficient

B. Total nitrogen, %	.926**	.985**	.851**	−.519	−.953**	.173	−.908**	.924**
—	B. Glutelin nitrogen, %	.878**	.694*	−.527	−.890**	.278	−.857**	.807**
—	−.525	B. Hordein nitrogen, %	.793**	−.447	−.939**	.208	−.897**	.875**
—	−.476	−.496	B. Salt-soluble nitrogen, %	−.579*	−.801**	−.099	−.740**	.966**
—	−.142	.435	−.307	B. 1000-kernel weight	.688*	−.294	.688*	−.552
—	−.062	−.004	.065	.746**	B. Starch, %	−.386	.961**	−.859**
—	.315	.218	−.477	−.242	−.742**	B. Insoluble residue, %	−.420	−.631*
—	−.102	−.036	.149	.605*	.752**	−.637*	B. Extract, %	−.769**
—	.336	−.535	.892**	−.221	.190	.256	.439	B. Wort nitrogen, %
—	−.021	.132	−.108	.623*	.249	.295	.277	−.107
—	−.079	.094	−.017	.652*	.797**	−.738**	.730*	.233
—	.045	.373	.378	.304	.218	−.162	.158	.247
—	.253	−.150	−.118	−.466	−.587	.531	−.203	−.138
—	.022	−.319	.305	.416	.625*	−.569	.854**	.475
—	−.062	.469	−.423	.276	−.221	.591	.022	−.386
—	−.006	.297	−.545	−.022	−.428	.670*	−.643*	−.692*
—	.300	−.010	−.296	−.446	−.420	.458	−.762**	−.566
—	−.078	.238	−.168	−.572	−.817**	.677*	−.674*	−.397

Partial correlation coefficient, independent of total nitrogen

** denotes that the 1% level and * that the 5% level of significance has been attained.

TABLE I

SIMPLE INTRAVARIETAL CORRELATION COEFFICIENTS AND CORRESPONDING PARTIAL CORRELATION COEFFICIENTS, INDEPENDENT OF TOTAL NITROGEN, FOR BARLEY AND MALT PROPERTIES

Simple correlation coefficient

.976**	−.637*	.694*	.764**	−.957**	.962**	.854**	−.269	.632*
.902**	−.613*	.655*	.769**	−.883**	.884**	.792**	−.140	.562
.972**	−.615*	.730**	.736**	−.958**	.969**	.888**	−.267	.654*
.818**	−.549	.427	.610*	−.767**	.757**	.578*	−.379	.469
−.390	.756**	−.173	−.654*	.600*	−.434	−.453	−.227	−.707*
−.914**	.793**	−.614*	−.843**	.967**	−.935**	−.881**	.135	−.794**
.232	−.670*	.002	.470	−.329	.326	.491	.388	.626*
−.861**	.814**	−.581*	−.749**	.973**	−.871**	−.915**	−.062	−.792**
.882**	−.520	.571	.672*	−.831**	.848**	.651*	−.457	.466
B. Diastatic activity (Papain), °L	−.626*	.671*	.771**	−.918**	.978**	.841**	−.302	.589*
−.232	B. Hours to steep to 44%	−.168	−.783**	.722**	−.661*	−.704*	−.269	−.881**
.160	.304	Malting loss, %	.343	−.704*	.702*	.701*	.189	.281
.039	−.595	.402	M. Wort nitrogen, %	−.716**	.819**	.607*	−.012	.802**
.248	.502	−.192	.073	M. Extract, %	−.931**	−.949**	.084	−.728**
.669*	−.228	.178	.447	−.143	M. Diastatic activity, (Lintner)	.879**	−.234	.690*
.070	−.400	.290	−.136	−.874**	.406	M. Proteolytic activity	.026	.728**
−.189	−.593	.542	.311	−.619*	.095	.510	M. Autolytic diastatic activity	.300
−.162	−.801**	−.282	.639*	−.547	.386	.467	.630*	M. Starch liquefying activity

Partial correlation coefficient, independent of total nitrogen

** denotes that the 1% level and * that the 5% level of significance has been attained.

Intravarietal Correlation Coefficients

In Table I the properties examined are listed along the diagonal axis and are prefixed with "B" or "M" to indicate whether the determination was made on barley or malt. The simple intravarietal correlation coefficients are listed in the upper right half of the table. The figure appearing in any particular section represents the simple correlation coefficient for the property listed on the left in the same line as the figure, and the property listed below in the same column as the figure.

The correlation coefficients were calculated from the means, over all varieties, for each station. Since 12 stations were included in the study, there were 12 pairs of values available for the calculation of each coefficient. Accordingly, there are 10 degrees of freedom and the 5% and 1% levels of significance correspond to values of .576 and .708. In the table a single asterisk denotes that the 5% level, and a double asterisk that the 1% level, of significance is attained.

Partial correlation coefficients, independent of total nitrogen, for the various pairs of properties, are listed in the lower left half of Table I. These will be discussed later. However, it may be noted, in passing, that for these correlations nine degrees of freedom are available and the 5% and 1% levels of significance correspond to values of .602 and .735, respectively.

Returning to the simple correlation coefficients it will be found that of the 153 coefficients listed, 72 are significant to the 1% level, 33 to the 5% level, and 48 fail to attain significance. Of the coefficients that fail to attain significance, 17 involve autolytic diastatic activity*, 13 involve insoluble residue of barley, and 8 involve 1000-kernel weight. These three categories account for all but 10 of the coefficients that fail to attain significance.

Examination of the top line of figures in Table I will show that, with the exception of the three properties mentioned above, total barley nitrogen is significantly correlated with all other properties. If the relations are checked for all the nitrogen fractions, it will be observed that all the simple correlation coefficients for these are similar in sign and magnitude to those for total nitrogen. This shows clearly that changes in environment that result in a regular change in total nitrogen also result in a regular change in nitrogen fractions (1, 10, 11). This regularity principle also appears to apply to the majority of the other barley and malt properties (9, 12–15, 19-21).

The numerical values of the coefficients furnish estimates of the degree to which changes in one property are paralleled by changes in the second property. With increasing nitrogen content of the barley all nitrogen fractions of both barley and malt show a highly significant tendency to increase in a regular manner. This also applies to the enzymatic activities and to a lesser extent to malting loss. On the other hand, the amounts of the principal fractions (barley starch, barley extract, and malt extract) including carbohydrates as

* For details of the methods used for measuring various properties, the reader is referred to earlier papers in this series. These are all listed at the end of this paper.

main constituents tend to decrease in a regular manner as nitrogen increases (9). The relations between these fractions and other properties exhibit a marked similarity to the corresponding relations with nitrogen fractions, but the former are invariably opposite in sign to the latter.

Although a change in environment that produces a change in a certain property also tends to produce a corresponding change in most other properties, certain irregularities almost invariably exist. For certain pairs of properties for which the correlation coefficients exceed .95, these irregularities are obviously small and may result mainly from experimental errors. However, for most pairs of properties, and particularly for those yielding correlation coefficients below .70, it is apparent that the associated effects of changing environment on the two properties are relatively loose. In these instances, it is only by making a very broad generalization that one can speak of parallel trends or a regularity principle.

It appears, however, that there are fundamental relations between certain pairs of properties that are so close that both properties must respond in a related manner to any change in environment. Some light on these relations can be obtained by calculating partial correlation coefficients, independent of total nitrogen. In effect, this procedure removes from consideration that part of the change in environment that is reflected by a change in total nitrogen. There remains that part of the environmental change that has no effect on total nitrogen. In other words, it is as though the correlation study were made with data on samples that, though of equal nitrogen content, were actually grown in different places and were thus presumably exposed to environmental conditions that differed in certain respects, however small. It will thus be apparent that, in some ways, the partial correlation coefficients provide a more stringent test of the associated effects of environment on any pair of properties.

A general examination of the partial correlation coefficients listed in Table I will show that 11 attain the 1% level of significance and 15 attain the 5% level. The corresponding figures for the simple correlation coefficients are 72 and 33.

Although space hardly permits a detailed discussion of all the significant partial correlation coefficients, there follow some general comments on the more important of these. As would be expected, close relations exist between the various carbohydrate fractions. Thus environmental conditions that tend to increase starch and barley extract also tend to increase malt extract and to decrease the insoluble barley residue which consists mainly of cellulose and lignin. On the other hand, these same environmental conditions appear to favour a reduction in proteolytic activity and autolytic diastatic activity. No reasonable explanation of these latter associations has been evolved.

Again, as might well be expected, a fairly close relation exists between salt-soluble barley nitrogen and wort nitrogen of barley, and it appears that a fundamental relation exists between these two properties. It seems surprising

TABLE II

SIMPLE INTERVARIETAL CORRELATION COEFFICIENTS AND CORRESPONDING PARTIAL CORRELATION COEFFICIENTS, INDEPENDENT OF SALT-SOLUBLE NITROGEN, FOR BARLEY AND MALT PROPERTIES

Simple correlation coefficient

B. Total nitrogen, %	.369	.811**	.238	−.552	−.399	.335	−.401	−.241
.562	B. Glutelin nitrogen, %	−.011	−.471	−.461	−.582*	.677*	−.590*	−.387
.829**	.027	B. Hordein nitrogen, %	.027	−.055	−.060	.033	−.115	.077
—	—	—	B. Salt-soluble nitrogen, %	−.348	.018	−.216	.109	.821**
−.515	−.359	−.048	—	B. 1000-kernel weight	.690*	−.613*	.639*	−.300
−.415	−.651*	−.061	—	.743**	B. Starch, %	−.950**	.983**	.312
.407	.668*	.040	—	−.752**	−.969**	B. Insoluble residue, %	−.969**	−.435
−.442	−.614*	−.119	—	.726*	.987**	−.974**	B. Extract, %	.413
.082	−.001	.095	—	−.206	.521	−.462	.570	B. Wort nitrogen, %
.024	.270	−.142	—	−.522	.145	.222	−.122	.074
.634*	−.022	.552	—	.050	−.240	.210	−.348	−.285
−.457	−.504	.128	—	.381	.634*	.256	.624*	.432
−.100	.459	−.305	—	−.420	−.163	.154	−.050	.395
−.563	−.769**	−.238	—	.714*	.948**	−.934**	.887**	.532
−.318	.171	−.500	—	−.362	−.241	.226	−.150	−.008
−.294	−.146	−.252	—	.163	.457	−.336	.508	.602
−.490	−.032	−.560	—	−.018	.323	−.334	.449	.554
−.415	.054	−.587	—	.227	−.301	−.226	.372	.540

Partial correlation coefficient, independent of salt-soluble nitrogen

** denotes that the 1% level and * that the 5% level of significance has been attained.

TABLE II

SIMPLE INTERVARIETAL CORRELATION COEFFICIENTS AND CORRESPONDING PARTIAL CORRELATION COEFFICIENTS, INDEPENDENT OF SALT-SOLUBLE NITROGEN, FOR BARLEY AND MALT PROPERTIES

Simple correlation coefficient

.199	.238	−.041	.166	−.381	−.039	.070	−.136	−.103
−.188	.336	−.637*	−.231	−.728**	−.239	−.474	−.381	−.310
.076	.505	.092	−.175	−.200	−.324	−.098	−.350	−.383
.739**	−.740**	.840**	.887**	.452	.727**	.874**	.751**	.727**
−.587*	.289	−.099	−.491	.439	−.486	−.230	−.272	−.107
.085	−.174	.359	−.060	.854**	−.153	.238	.227	.194
−.014	.298	−.048	−.122	−.913**	.006	−.348	−.378	−.309
−.001	−.313	.428	.074	.914**	−.024	.340	.377	.333
.635*	−.717**	.856**	.833**	.642*	.594*	.885**	.825**	.809**
B. Diastatic activity (Papain), %	−.706*	.436	.735**	.288	.904**	.634*	.751**	.750**
−.352	B. Hours to steep to 44%	−.706*	−.806**	−.589*	−.814**	−.823**	−.937**	−.954**
−.505	−.231	Malting loss, %	.748**	.688*	.465	.915**	.700*	.697*
.254	−.483	.013	M. Wort nitrogen, %	.431	.829**	.874**	.849**	.801**
−.076	−.424	.637*	.073	M. Extract, %	.325	.644*	.653*	.592*
.800**	−.596	−.391	.579	−.006	M. diastatic activity (Lintner)	.662*	.856**	.816**
−.030	−.536	.689*	.448	.570	.087	M. Proteolytic activity	.807**	.798**
.441	−.859**	.194	.602	.533	.684*	.473	M. Autolytic diastatic activity	.975**
.460	−.922**	.231	.493	.437	.610*	.399	.946**	M. Starch liquefying activity

Partial correlation coefficient, independent of salt-soluble nitrogen

** denotes that the 1% level and * that the 5% level of significance has been attained.

that the partial correlation coefficients for barley diastatic activity as determined in the presence of papain, and malt diastatic activity (.67) are not higher. It will be observed, however, that the corresponding simple correlation is very high (.98). The explanation appears to be that diastatic activity is controlled mainly by those environmental factors that also control total nitrogen content. When these are removed from consideration, by calculating the partial correlation coefficient independent of total nitrogen, the remaining environmental factors have little influence on diastatic activity and hence the possible relation between values for barley and malt is partially obscured by the greater relative importance of random variations contributed by experimental errors.

The property reported in terms of the number of hours required to steep barley to a moisture content of 44%, shows some interesting associations with other properties. Steeping time appears to be increased by those environmental conditions that tend to increase 1000-kernel weight and starch content, and to decrease insoluble barley residue. Steeping time is obviously affected by kernel size but it also appears to be affected by the texture of the kernel.

It is also interesting to note that steeping time is inversely correlated with the starch liquefying activity of the malt, and that the latter is inversely correlated with the starch content of the barley. Whether environmental conditions that tend to increase starch content also tend to change the texture of the kernel, or the nature of the starch grains, so as to slow down the rate of absorption of water and the rate of enzyme attack, or whether these environmental conditions actually decrease the amounts and activity of the starch liquefying enzyme, is not clear. However, some fairly close association appears to exist between these three properties.

In general, the study of the intravarietal relations between various barley and malt properties shows that those environmental factors that affect total nitrogen content also affect most other properties to a greater or lesser extent. Thus when working with samples of one variety, or of a group of closely similar varieties, a determination of nitrogen content provides considerable information on the general malting qualities of the sample. However, if an attempt were made to predict malting quality from nitrogen content alone, considerable variations would be obtained from expected results for certain properties, since these are obviously controlled to a considerable extent by environmental factors that have little effect on total nitrogen content. Among these various properties, there are certain pairs that obviously respond in an associated manner to changes in environment. In some instances this type of association represents an obvious fundamental relation between the properties concerned. In other instances, the nature of the association is by no means clear and the question of whether or not a fundamental relation exists must await the results of further investigation.

Intervarietal Relations

The simple intervarietal correlation coefficients for the barley and malt properties examined are listed in the upper right half of Table II. These were calculated from the means, over all stations, for each variety. Since 12 varieties were studied, there were available for each correlation 12 pairs of values, corresponding to 10 degrees of freedom and 5% and 1% points of .576 and .708.

Among the 153 simple correlation coefficients listed in Table II, 43 attain the 1% level of significance, 22 attain the 5% level, and 88 are of negligible magnitude in that they fail to attain this latter level of significance. For reasons that will be discussed later, partial correlation coefficients, independent of salt-soluble barley nitrogen, are given in the lower left half of the table.

The intervarietal correlations between barley and malt properties result from associated effects of genetic or hereditary factors on various pairs of properties. It is not surprising that these associated effects should differ considerably from the effects of environmental factors, and that appreciable differences should thus exist between intra- and intervarietal correlation coefficients for corresponding pairs of properties. The most striking differences occur in the coefficients for total nitrogen and nitrogen fractions, and in the coefficients for these and the remaining properties. Whereas most of the intravarietal correlation coefficients are highly significant (Table I), most of the intervarietal correlation coefficients, given in Table II, fail to attain a significant level. Thus there is no evidence for intervarietal regularities in composition between nitrogen fractions (1, 10, 11) or between nitrogen fractions and carbohydrates (9, 21).

On the other hand, as would be expected, close intervarietal associations exist between starch content, insoluble barley residue, barley extract, and malt extract (9, 15, 21). There is also a definite indication that varieties that tend to show high activity with respect to one type of enzyme also tend to show high activities with respect to other enzymes.

While salt-soluble barley nitrogen shows no significant correlation with total nitrogen, the other barley nitrogen fractions, starch, barley extract, or malt extract, it is closely associated with wort nitrogen of both barley and malt and also with all the enzymatic activities, with malting loss, and with steeping time. It appears that barley varieties that are high in salt-soluble nitrogen tend to be high in enzymatic activity, in wort nitrogen, and in malting loss, and that they also tend to absorb water more rapidly in the steep.

The associations among these various properties that are correlated with salt-soluble nitrogen suggest that hereditary factors that express themselves by controlling salt-soluble nitrogen may also play a part in controlling a number of other barley and malt properties, particularly those associated with enzymatic activities. In order to clarify the associations that appear to exist among the various properties that are correlated with salt-soluble nitrogen, and to bring to light other associations that might be masked by

bilateral associations with salt-soluble nitrogen, the partial correlation coefficients, independent of salt-soluble nitrogen, were calculated for each pair of properties. These partial correlation coefficients are listed in the lower left half of Table II. This calculation removes the effects of those genetic factors that express themselves by controlling salt-soluble nitrogen content. If the remaining genetic factors have associated effects on any pair of properties, there is obtained a significant partial correlation coefficient that provides evidence of a relation, between the properties represented, that is independent of bilateral associations between each of the two properties and salt-soluble nitrogen.

Of the 146 partial correlation coefficients, 14 attain the 1% level of significance, 12 attain the 5% level, and the remainder are not significant. The corresponding figures for the simple correlation coefficients are 43 and 22. An examination of the significant partial correlation coefficients shows that of the 14 that attain the 1% level, 12 are of the same order of magnitude as the simple coefficients, and two represent increases from the 5% level; and of the 12 partial correlation coefficients that attain the 5% level, 3 represent decreases from the 1% to the 5% level, and 4 represent rises from below to above the 5% level.

Among the coefficients that remain relatively unchanged by removal of effects associated with salt-soluble nitrogen, the majority involve associations between carbohydrate fractions, total nitrogen, glutelin nitrogen, and hordein nitrogen, on the one hand, and certain other fractions, on the other hand. In general, it appears that genetic factors that control these properties have little influence on salt-soluble nitrogen.

Where there exist appreciable differences between the magnitudes of the simple and partial correlation coefficients, the properties involved are mainly enzymatic activities, wort nitrogen, malting loss, and steeping time. Intervarietal associations between each of these properties and salt-soluble nitrogen obviously exist, but whereas the simple correlation coefficients suggest that associations exist among all these properties, the partial correlation coefficients show that real associations, independent of common associations, with salt-soluble nitrogen, only exist in fact for certain pairs of these properties. In this category may be classed the following pairs of properties:—diastatic activities of barley and malt; malting loss and proteolytic activity; autolytic diastatic activity and steeping time, and diastatic activity of malt; starch liquefying activity and each of the two last named properties; and starch liquefying activity and autolytic diastatic activity. Fundamental relations appear to exist between these pairs of properties, so that, with respect to each pair, certain genetic factors that control one property also appear to control the other and varieties that are high in one property thus tend to be high (or low if the relation is inverse) in the other property.

For certain other pairs of properties, e.g., proteolytic activity and diastatic activity of barley or malt, the apparent association suggested by a significant simple correlation coefficient, turns out to be a superficial reflection of the

associations that exist between each property and salt-soluble nitrogen. Accordingly, the partial correlation coefficient, independent of salt-soluble nitrogen, fails to attain significance. In these instances it seems safe to assume that certain genetic factors are common to the control of salt-soluble nitrogen and one member of the pair of properties in question; that these factors or others are also common to the control of salt-soluble nitrogen and the second property of the pair; and that there are few or no genetic factors that do not control salt-soluble nitrogen but are common to the control of both properties forming the pair under consideration. Under these conditions, it would appear that between each pair of properties of this type (i.e., giving a significant simple correlation coefficient but failing to give a significant partial correlation coefficient, independent of salt-soluble nitrogen) there exists no fundamental relation, nor any appreciable association other than that which each property has with salt-soluble nitrogen.

Calculation of Additional Correlation Coefficients

The simple correlation coefficients given in Tables I and II can be used to calculate a very large number of other correlation coefficients that may serve to shed additional light on certain of the inter- and intravarietal associations that exist between various barley and malt properties. Some of the more interesting of these associations have been discussed in greater detail in earlier papers in this series, but it seems probable that other investigators may be interested in certain associations that we have not examined. The statistics given in Tables I and II may prove useful for these purposes.

The partial correlation coefficient for any two of the properties listed, independent of any third property, can be calculated from the following formula:—

$$r_{12\cdot 3} = \frac{r_{12} - r_{13} \cdot r_{23}}{\sqrt{(1 - r^2_{13})\,(1 - r^2_{23})}}$$

where $r_{12\cdot 3}$ is the partial correlation coefficient for Properties 1 and 2, independent of Property 3; and r_{12} is the simple correlation for Properties 1 and 2, etc. Since all the simple correlation coefficients were calculated from 12 pairs of values, there are 9 degrees of freedom for partial correlation coefficients involving 3 variables, and the 5% and 1% points are therefore .602 and .735.

The simple and partial correlation coefficients can also be used to calculate multiple correlation coefficients. For coefficients involving three variables the following equation may be used:—

$$1 - R^2_{1\cdot 23} = (1 - r^2_{12})\,(1 - r^2_{13\cdot 2})$$

where $R_{1\cdot 23}$ is the multiple correlation coefficient for Property 1 with Properties 2 and 3, and r_{12} and $r_{13\cdot 2}$ are the appropriate simple and partial correlation coefficients. There are nine degrees of freedom for the multiple correlation coefficient involving three variables and the 5% and 1% points are .697 and .800. It should be noted that with the data presented in this paper, it is

not possible to determine whether the multiple correlation coefficient is significantly greater than the corresponding simple correlation coefficient. Experience must serve as a guide in assessing the usefulness of adding the second independent variable. Multiple correlation coefficients involving more than three variables can also be calculated but the calculations become tedious and will hardly be worth undertaking in view of the limited number of degrees of freedom.

Generally speaking, the intravarietal correlation coefficients, given in Table I or calculated from these statistics, will be of most interest to the practical maltster. In almost all countries single varieties or mixtures of closely related varieties are used for malting purposes. Thus the practical maltster is interested primarily in the effects of environment on malting quality and in the relations between various properties that exist within one variety or closely related group of varieties.

The intervarietal correlation coefficients, given in Table II or calculated from these statistics, will be of more interest to the plant breeder and to the cereal chemist who is assisting in the development of new malting barleys. With a thorough knowledge of the intervarietal relations and associations that exist between barley and malt properties, it is possible to form a fairly reliable judgment of the comparative malting qualities of new varieties from the results of analysis of the barley. In the early stages of a breeding program it should be possible to do without the malting test, which requires so much time and special equipment, without danger of discarding new lines with superior malting qualities. Experience has already shown that by a judicious use of barley analysis and malting tests, fortified by a knowledge of the intervarietal relations between barley amd malt properties, the malting chemist can assist the plant breeder materially in his task of developing superior varieties of malting barley.

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THE PHYTOPLANKTON OF SOUTHERN AND CENTRAL SASKATCHEWAN

PART I[1]

By Paul E. Kuehne[2]

Abstract

Plankton collections from 58 lakes of the Prince Albert Park and the southern half of Saskatchewan yielded 292 species and varieties of algae, among them *Chaetoceros Elmorei, Nodularia spumigena,* and a new variety of *Lyngbya Birgei.* The lakes, chemically alkaline, are classified as freshwater and saline, and the various classes of algae are briefly discussed with reference to these two types of lakes. A list of the species collected is given, showing localities and relative abundance of each type.

Phycological literature offers very little on the algal flora of Saskatchewan: a paper on the diatoms of the Quill lakes (1), the names of several other algae from the same lakes (14), and some occasional references to those of Carlyle Lake (17). Yet, the algae, and especially the plankton algae, play a vital role in aquatic ecology. They are, to paraphrase H. G. Wells, "the base of the lake's vital pyramid, on which are supported almost all our food fishes". To contribute to a knowledge of the algal flora is the purpose of this paper.

The material was collected by Dr. D. S. Rawson in nine lakes and two creeks of the Prince Albert Park in the years 1928–31, and by J. E. Moore, in the years 1938 and 1939, in 47 lakes (Fig. 1) scattered throughout the southern half of the province. Detailed chemical and physical studies of these lakes have been made by the collectors (21, 22, 28). All lakes have a pH value above 7 and are, therefore, alkaline in the strictly chemical sense. But for limnological reasons, they are divided into two groups, saline (popularly called "alkaline") and freshwater. This classification is based upon the total solid content of the waters. Lakes with a concentration of more than 300 mg. of solids per litre of water (or, as usually stated, of more than 300 p.p.m.) are considered saline, and those with less than 300 p.p.m. as freshwater. On this basis, the lakes of the Prince Albert Park are freshwater, whereas all but five of those studied by Mr. Moore belong to the saline group (Table I). Dr. Rawson and Mr. Moore generously permitted the study of their collections and were ever ready to supply requested information. The author takes this opportunity of expressing to them his sincere thanks.

No new species are described in this paper, but a new variety of *Lyngbya Birgei* has been established. Many of the forms listed have previously been reported from adjacent regions, and almost all of them occur in North America. Some are included as doubtful because of insufficient or poorly preserved material. With few exceptions, motile forms have been excluded. Several collections, for instance, contained *Chlamydomonas, Euglena,* and other forms

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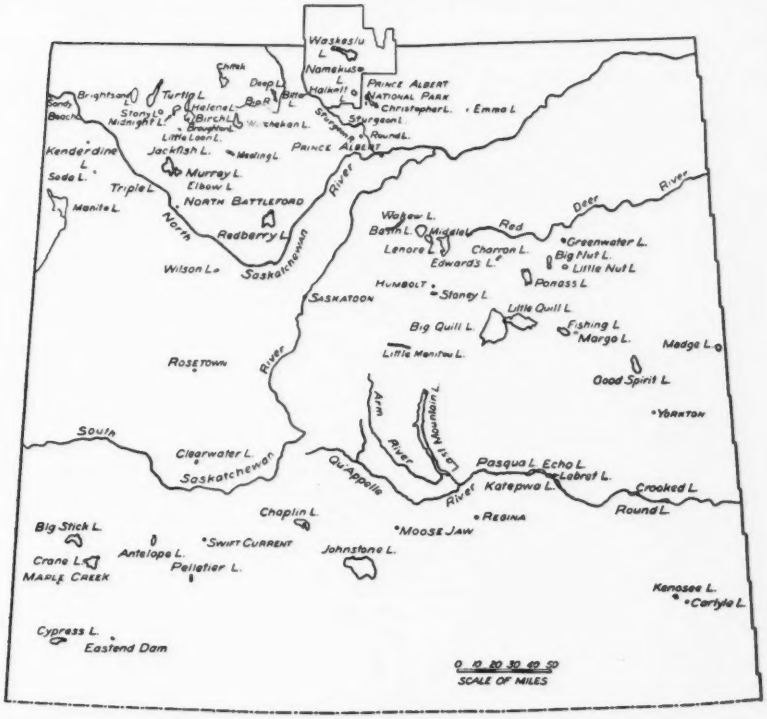

FIG. 1. *Sketch map showing distribution of lakes in southern Saskatchewan. By J. E. Moore.*

apparently motile when alive, but their state of preservation did not permit specific identification. Filaments, representing several species of *Spirogyra*, were found in many collections, but all in the sterile condition.

The collections from Little Manitou Lake contained much material of a minute, branching alga (Figs. 2 and 3). The general vegetative characteristics, such as mode of branching, diameter of the cell, etc., pointed to that strange Phaeophycean, *Pleurocladia lacustris*, which has been reported only from lakes in northern Germany (24). Some specimens, however, showed akinete-like structures, unknown in that brown alga. Dr. W. R. Taylor*, to whom the material was submitted, at first shared this opinion. In a later communication he suggested that the plant might be *Ctenocladus*, a brackish Chlorophycean, found in some pools near Mariana, California, in 1929 (32). This alga has cell series rather like the "akinetes" of the Saskatchewan specimens, but is lacking in other characters. Dr. Taylor rightly added, "So much of the point of view depends on the color!" Only fresh specimens, promptly

* *Personal communication.*

TABLE I

TOTAL NUMBER OF SPECIES AND VARIETIES AND OTHER DATA FOR EACH LAKE

Lakes	Max. depth, ft.	Total solids, p.p.m.[1]	Number of species					Dates	Collecting methods[2]		
			Cyanophyceae	Chlorophyceae	Bacillarieae	Miscellaneous[3]	Total		ST	TV	STL
A. Saline											
Antelope	28	13,640	8	6	4	0	18	7/30/38	*	*	
								8/12/39			*
Atten	27	1394	3	2	19	3	27	5/31/39			*
Basin	35	11,805	7	7	4	2	20	6/30/39	*	*	*
Big Quill	20	30,022	11	5	8	3	27	9/ 2/38	*		
								7/ 3/39	*	*	
Birch	13	636	20	12	14	4	60	6/15/39	*	*	*
								8/ 1/39	*		*
Bitter	55	13,981	7	0	19	2	28	5/26/39	*	*	*
Brightsand	22	452	2	7	43	3	55	6/ 9/39	*	*	*
								7/30/39			*
Carlyle	50	1341	2	1	4	1	8	7/ 1/38	*	*	
Christopher	33	542	10	8	20	5	43	6/27/39	*	*	*
Clearwater	32	781	6	9	4	2	21	7/27/38	*	*	
Echo	57	1231	16	17	39	1	73	6/23/38	*	*	
								5/20/39	*	*	*
								7/ 7/39	*	*	*
								8/30/39			*
Edwards	13	894	4	1	1	3	9	7/15/38	*	*	
Emma	30	528	12	5	24	4	45	6/27/39	*	*	*
Fishing	35	3183	21	10	25	4	60	7/10/38	*	*	
								7/ 1/39	*	*	*
Good Spirit	13	868	11	4	6	1	22	7/ 5/38	*	*	
Greenwater	25	357	17	9	16	3	45	7/13/38	*	*	
								7/ 1/39	*	*	*
Jackfish	15	1172	17	20	34	2	73	8/11/38	*	*	
								5/29/39	*	*	*
								7/19/39	*	*	*
Kenderdine	38	1013	22	27	25	5	79	8/20/38	*	*	
								6/ 2/39	*	*	*
								7/22/39	*	*	*
Kenosee	25	1186	3	1	6	1	11	6/29/38	*	*	
Last Mountain	80	2416	24	21	32	4	81	6/14/38	*	*	
								5/18/39	*	*	*
								7/ 5/39	*	*	*
								8/29/39	*		*
Lenore	23	5486	11	12	6	1	30	7/17/38	*	*	
Little Loon	33	352	8	3	18	2	31	6/14/39	*	*	*
Little Manitou (north of Watrous)	12	115,500	2	5	5	1	13	5/16/39			*
								7/ 4/39	*	*	*
								8/28/39	*	*	
Little Quill	5	21,387	10	6	15	3	34	9/ 2/38	*		
								7/ 2/39			*
Madge	43	412	11	5	7	1	24	7/ 8/38	*	*	
Manito	75	19,233	3	5	7	3	18	8/17/38	*	*	
								5/10/39			*
								5/31/39			*
								6/ 1/39			*
								7/24/39			*
Margo	11	1497	15	13	18	1	47	7/10/38	*	*	
								7/ 2/39	*	*	*

TABLE I—*Continued*

TOTAL NUMBER OF SPECIES AND VARIETIES AND OTHER DATA FOR EACH LAKE—*Continued*

Lakes	Max. depth, ft.	Total solids, p.p.m.[1]	Number of species					Dates	Collecting methods[2]		
			Cyanophyceae	Chlorophyceae	Bacillarieae	Miscellaneous[3]	Total		ST	TV	STL
A. Saline—*concluded*											
Midnight	10[3]	448	11	9	10	2	32	7/31/39			*
Murray	19	751	22	13	30	5	70	8/12/38	*	*	
								5/29/39	*	*	
								6/ 7/39			*
								8/17/39	*	*	*
								8/18/39	*		
Pasqua	60[3]	995	11	9	16	0	36	7/ 8/39			*
Pelletier	27	461	9	7	6	3	25	7/29/38	*	*	
Redberry	80	13,666	10	12	12	2	36	8/25/38	*	*	
								6/17/39	*	*	*
								8/ 7/39	*	*	
Round I (Qu'Appelle Valley)	38	887	10	3	4	3	20	6/28/38	*	*	
Round II (northwest of Prince Albert)	20	1307	7	5	11	2	25	6/23/39	*	*	*
Sandy Beach	40[4]	1547	2	2	7	1	12	7/23/39			*
Soda	7	9318	0	5	9	3	17	6/ 2/39			*
								7/21/39	*	*	*
Stoney (south of Humboldt)	17	6787	6	2	3	1	12	7/18/38	*	*	
Stony (northwest of Glaslyn)	10	412	19	13	15	4	51	8/ 3/39	*	*	*
Sturgeon	27	486	14	3	15	4	36	6/24/39	*	*	*
Wakaw	30	2915	11	2	19	0	32	5/23/39	*	*	*
Wilson	22	907	12	6	1	0	19	8/ 8/38	*	*	
Witchekan	10[3]	838	10	13	9	1	33	8/ 4/39			*
Total—Saline lakes			51	81	103	11	246				
B. Freshwater											
Bagwa (P. A. Park)	?	?	11	0	2	0	13	9/ 3/28	*		
Beartrap Creek (P. A. Park)	?	?	0	5	6	1	12	8/13/28	*		
Broughton	17	171	15	8	11	2	36	8/ 2/39	*	*	*
Crean (P. A. Park)	89	?	10	8	21	4	43	6/15/31		*	
								7/23/31		*	
								8/24/31		*	
								9/17/31		*	
Deep	78	295	1	3	25	2	31	5/25/39	*	*	*
Halkett (P.A. Park)	173	283	17	18	18	4	57	7/28/30	*	*	
								9/ 3/30	*		
								8/11/31		*	
Helene	18[3]	217	10	14	34	2	60	6/15/39	*	*	*
Kingsmere (P. A. Park)	154	?	14	12	14	5	45	6/28/28	*		
								8/28/28	*	*	
								9/ 3/28	*		
								6/ 8/31		*	
								7/17/31		*	
								8/18/31		*	
								9/14/31		*	

TABLE I—*Concluded*

TOTAL NUMBER OF SPECIES AND VARIETIES AND OTHER DATA FOR EACH LAKE—*Concluded*

Lakes	Max. depth, ft.	Total solids, p.p.m.[1]	Number of species					Dates	Collecting methods[2]		
			Cyanophyceae	Chlorophyceae	Bacillarieae	Miscellaneous[5]	Total		ST	TV	STL
B. Freshwater —*concluded*											
Lavallee (P. A. Park)	46	?	9	6	7	2	24	7/29/29	*		
Meeting	43	231	18	16	16	2	52	7/ 5/39	*	*	*
Moose Creek (P. A. Park)	?	?	11	7	7	2	27	7/27/28	*		
Shady (P. A. Park)	?	?	13	6	3	1	23	8/21/28	*		
Tibiska (P.A. Park)	44	?	9	7	6	3	25	8/ 2/29	*		
Turtle	45	261	18	19	37	2	76	6/12/39	*	*	*
								7/27/39	*	*	*
Wabeno (P. A. Park)	?	?	4	7	10	4	25	9/ 7/29	*		
Waskesiu (P. A. Park)	80	178	34	52	25	5	116	7/ 3/28		*	
								7/27/28	*	*	
								8/ 3/28	*		
								8/13/28	*	*	
								8/17/28	*	*	
								9/ 7/28		*	
								9/15/28	*		
								7/ 2/29		*	
								7/ 8/29	*		
								8/30/29	*		
								6/29/31		*	
								7/20/31	*	*	
								8/ 2/31		*	
								9/ 1/31		*	
Waskesiu (Narrows)			8	0	1	0	9	9/10/31	*		
Total—Freshwater lakes			43	75	71	8	197				
Total—All lakes			57	112	111	12	292				

[1] *Total solid content of water in parts per million (cf. text).*
[2] ST = *surface tow;* TV = *total vertical haul;* STL = *surface tow in littoral region.*
[3] *Estimated value; not measured at time of collecting.*
[4] *Reported value; not measured at time of collecting.*
[5] *Heterokontae, Chrysophyceae, Dinophyceae.*

examined, can furnish that information. Furthermore, a knowledge of the various reproductive structures and of the life history are very desirable. Such investigations are planned.

In Table I are given the number of species and varieties collected in each lake and the total for all the lakes. Even with the inclusion of all forms omitted from this discussion, the plankton flora of the Saskatchewan lakes can scarcely be regarded as rich. The following considerations may account for this apparent poverty.

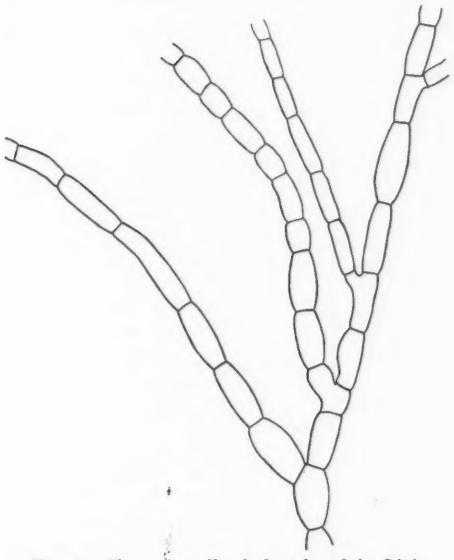

FIG. 2. *Vegetative cells of plant found in Little Manitou Lake. 247×.*

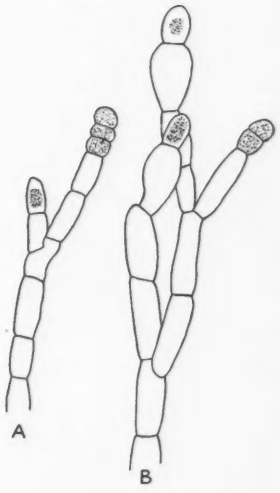

FIG. 3. *Akinete-like terminal cells of plant found in Little Manitou Lake. Type A more frequent than Type B. 247×.*

All collections were made with plankton nets of No. 20 silk bolting cloth. This mesh allows most of the minute organisms, such as *Ankistrodesmus*, *Oocystis*, *Crucigenia*, *Cocconeis*, and *Cyclotella* spp., to pass through the net. To obtain them in appreciable quantities, if at all, the lake water would have to be centrifuged, though a cotton disk serves as a fairly efficient substitute (3). No samples were taken by these methods, because the original investigations were primarily ecological, not systematic.

For most of the saline lakes and for some of the freshwater type, two methods of collecting were employed, the surface tow and the total vertical haul. "In the first case the net was towed behind the boat, which was rowed slowly, for a period of three minutes. In making a vertical haul the net was pulled up from the bottom of the lake at the rate of approximately one-half metre per second" (21). Blue-green and green algae were usually more numerous in the surface tow, and the diatoms in the vertical haul; in most cases, however, the difference was not very striking. This, no doubt, is due to the shallowness of most lakes and, in the deeper lakes, perhaps, to a narrow epilimnion at the time of collecting.

Most lakes are represented by collections made in a single day. Yet, as is well known, owing to such variable factors as temperature, intensity of light, supplies of nitrates, phosphates, and other dissolved nutrient materials, presence of predators, etc., the plankton constitutes an ever changing popu-

TABLE II

OCCURRENCE OF THE MORE COMMON ALGAE OF WASKESIU LAKE

Species	1928										1929			1931				
	July			Aug.					Sept.		July		Aug.	June	July		Aug.	Sept.
	3	27	27	3	13	13	17	17	7	15	2	8	30	29	20	20	8	1
	TV	ST	TV	ST	ST	TV	ST	TV	TV	ST	TV	ST	ST	TV	ST	TV	TV	TV
Cyanophyceae:																		
Anabaena																		
circinalis	1*	1	–	–	1	–	2	–	1	1	–	–	3	2	–	1	–	2
Lemmermanai	1	3	2	4	1	–	3	2	2	2	1	1	3	2	2	1	–	2
spiroides	–	–	–	–	–	–	–	1	2	–	–	1	3	–	–	1	–	–
Lyngbya																		
limnetica	1	1	1	–	–	2	1	–	–	–	2	1	1	4	–	5	4	2
Coelosphaerium																		
Naegelianum	1	2	1	3	3	1	3	1	2	3	–	2	3	1	3	2	–	1
Aphanocapsa																		
pulchra	1	1	1	1	2	–	2	–	2	2	1	2	2	–	–	–	2	2
elachista var. conferta	2	1	–	–	1	–	3	2	2	3	–	1	2	–	1	2	1	–
Microcystis																		
aeruginosa	–	1	–	1	1	1	2	–	–	3	1	2	3	1	–	2	–	2
Chlorophyceae:																		
Pediastrum																		
Boryanum	2	2	2	2	2	1	1	1	2	1	2	3	2	2	2	2	2	2
duplex	–	2	–	2	1	–	–	–	–	–	1	2	1	2	2	1	–	–
duplex var. clathratum	–	1	–	2	2	1	1	–	2	–	2	2	2	1	1	1	–	1
Staurastrum																		
paradoxum	2	–	2	–	–	–	–	–	1	1	1	1	–	–	2	–	1	–
longiradiatum	–	2	–	1	2	1	1	2	1	1	1	1	–	–	–	1	2	–
Sphaerocystis																		
Schroeteri	–	–	–	–	3	2	3	1	1	2	1	1	2	–	1	1	–	1
Dictyosphaerium																		
pulchellum	–	–	–	–	–	–	–	–	1	–	3	2	1	–	–	2	1	1
Bacillarieae:																		
Melosira																		
granulata	4	3	2	2	1	2	2	2	3	4	5	4	1	4	2	5	3	4
crenulata	3	3	–	–	2	–	–	2	2	2	2	–	–	1	1	1	2	–
Stephanodiscus																		
niagarae	1	2	–	3	2	2	3	2	3	4	3	3	2	4	3	3	2	3
Fragilaria																		
crotonensis	4	3	3	–	–	2	3	1	3	3	3	4	1	3	3	2	2	2
capucina	2	–	2	–	–	–	–	1	1	–	3	2	1	2	1	1	–	–
Tabellaria																		
fenestrata	–	1	1	–	–	1	1	1	1	–	2	2	–	1	–	1	2	2
Asterionella																		
formosa	–	1	1	–	–	1	1	–	2	1	2	–	2	–	–	–	–	2
Miscellaneous:																		
Dinobyron																		
divergens	3	2	2	–	–	1	–	2	–	2	2	–	–	2	2	–	3	–
Ceratium																		
hirundinella	3	4	3	4	4	3	4	2	3	2	1	2	1	–	3	1	2	3

NOTE: "ST" *and* "TV" *after the dates denote surface tow and total vertical haul, respectively (cf. text).*

* *These numbers indicate the relative abundance in the sample:* 1 = *rare,* 5 = *very abundant.*

lation. Some forms are present during one month, scarce during the next, and back again during the third when environmental conditions have again become favourable (Table II). To obtain a fairly representative picture of the plankton flora of a given lake, collections should be made on several days, distributed throughout the year. The results from the lakes in which more than one collection was made may be offered in confirmation of this; in Echo Lake 73 species were collected in four days; in Kenderdine 79 species in three days; in Last Mountain 81 species in four days; and in Waskesiu 116 species in 14 days.

Owing to the short summer in the Saskatchewan region, most of the algae have only a single maximum. Ricker (29) and others, however, found that many diatoms have two; but, since they come early and late in the year, the Saskatchewan collections did not show this. Oltmanns (23) states that in northern regions *Ceratium* is likewise bimodal. This was found to be true only in Kingsmere Lake, though the collections from Waskesiu for 1931 also demonstrated this to some degree.

In one year only (1939) samples were taken also from the littoral regions. Plankton catches are usually restricted to the open water, because many of the littoral forms are not true *plankton* organisms; that is, organisms that "remain suspended in the water during their entire existence". Certain algae, however, such as *Oedogonium*, *Spirogyra*, *Ulothrix*, and *Cladophora*, are epiphytic in their early stages, and only become free floating tangles later in the season, bearing epiphytes and sheltering unicellular and colonial organisms. They may then drift into the open water and thus form part of the plankton. Economically they are, of course, important because, "the young fish of very many species live in this habitat and are almost wholly dependent upon the small organisms as a food supply following the absorption of the yolk sac" (2). No such floating tangles were encountered, but the littoral collections yielded a large number of species, especially diatoms, that otherwise would have been left unrecorded.

A List of the Plankton Algae Collected in Southern and Central Saskatchewan

The scheme of classification in the following list is that used in Smith's *Fresh-water Algae of the United States* (32), the only book that describes all the genera known to occur in the United States and probably also in the southern parts of Canada. For each species, the numbers 1 to 5 after the name of each lake indicate the relative abundance of that particular form in the collections: 1, rare; 2, occasional; 3, common; 4, abundant; 5, very abundant. The lakes that are represented by more than one collecting day have two numbers, to show the range. For these, the figure "0" implies that on some days no specimens were found.

After each specific name are listed one or more authors who give a complete and authoritative description of that form and, in most instances, satisfactory illustrations. Boyer (5) shows no illustrations but refers to numerous sources

of information. For the desmids two references are usually cited, (34) and (31), though in many instances the dimensions of the Saskatchewan specimens come only within the limits given in the first. This is especially true of the various *Closterium* species.

The content of the list is summarized as follows:

Classes	Families	Genera	Species and varieties
Cyanophyceae	5	19	57
Heterokontae	3	3	3
Chrysophyceae	1	1	4
Bacillarieae	12	34	111
Chlorophyceae	16	40	112
Dinophyceae	1	3	5
Total	38	100	292

The Cyanophyceae and Chlorophyceae are discusssd in Part I of this paper.

CYANOPHYCEAE

The blue-green algae are well represented in both types of lakes and form the dominant organisms during the warmest months of the year. *Anabaena*, *Aphanizomenon*, *Gloeotrichia*, and *Microcystis* are absent in the highly saline lakes. In some of the less saline lakes, however, they may become so abundant as to form a "water bloom". Such blooms usually consist of several genera with one or two species dominating. The following lakes showed a more or less heavy bloom of certain algae.

Bagwa: *Anabaena*, *Aphanizomenon*, *Lyngbya*.

Greenwater: *Anabaena*, *Aphanizomenon*, *Gloeotrichia*.

Margo: *Gloeotrichia*, *Microcystis*.

Murray: *Anabaena*, *Microcystis*.

Shady: *Aphanizomenon*, *Anabaena*, *Volvox*.

Waskesiu Narrows: *Anabaena*, *Aphanizomenon*, *Microcystis*.

Moose Creek, near its entrance into Waskesiu, also had a heavy bloom of *Anabaena* spp. with some *Microcystis* and *Aphanizomenon*. In Antelope Lake, *Chroococcus minutus* was so abundant in 1938 as to almost constitute a bloom.

CHROOCOCCACEAE

Chroococcus dispersus (v. Keiss.) Lemm. (30, p. 28, Pl. 1, Fig. 2; 11, p. 84, Fig. 84).

Big Quill (0–3), Bitter (1), Broughton (2), Fishing (0–1), Halkett (0–1), Helene (1), Jackfish (0–1), Kenderdine (0–1), Kingsmere (0–1), Last Mountain (0–2), Lenore (1), Pelletier (2), Waskesiu (0–2).

Chroococcus dispersus var. **minor** G. M. Smith (30, p. 28, Pl. 1, Fig. 3; 11, p. 84).

Big Quill (0–2), Last Mountain (0–2), Little Quill (0–1), Manito (0–1), Meeting (1), Stony (2), Turtle (0–1), Waskesiu (0–1).

Chroococcus limneticus Lemm. (30, p. 29, Pl. 1, Fig. 4; 11, p. 82, Fig. 82; 10, p. 40, Fig. 44).

Antelope (0–1), Big Quill (0–1), Birch (3–4), Bitter (1), Brightsand (1–2), Broughton (2), Christopher (2), Echo (0–3), Emma (3), Fishing (0–2), Good Spirit (1), Greenwater (1–2), Halkett (0–1), Helene (2), Jackfish (0–3), Kenderdine (0–1), Last Mountain (0–2), Little Loon (3), Meeting (2), Midnight (3), Moose Creek (1), Murray (2–3), Pelletier (2), Redberry (0–1), Sandy Beach (1), Stoney (2), Stony (3), Sturgeon (2), Tibiska (2), Turtle (1–3), Wakaw (1), Waskesiu (0–2), Witchekan (1).

Chroococcus limneticus var. **carneus** (Chod.) Lemm. (30, p. 30, Pl. 1, Fig. 6; 11, p. 84).

Last Mountain (0–1).

Chroococcus limneticus var. **distans** G. M. Smith (30, p. 30, Pl. 1, Fig. 7; 11, p. 84).

Fishing (2), Last Mountain (0–1), Meeting (1), Waskesiu (0–2).

Chroococcus limneticus var. **subsalsus** Lemm. (30, p. 29, Pl. 1, Fig. 5; 11, p. 84).

Big Quill (2), Birch (3), Christopher (1), Clearwater (1), Emma (2), Fishing (1), Good Spirit (2), Greenwater (0–1), Jackfish (0–1), Kenderdine (0–1), Lavallee (2), Lenore (1), Little Loon (1), Meeting (2), Midnight (2), Stony (3), Sturgeon (3), Turtle (0–2), Waskesiu (0–2), Wilson (2), Witchekan (3).

Chroococcus minutus (Kütz.) Näg. (30, p. 28, Pl. 1, Fig. 1; 11, p. 79, Fig. 74).

Antelope (3–4), Broughton (1), Crean (0–1), Echo (0–4), Halkett (0–2), Jackfish (0–1), Kenderdine (0–2), Kingsmere (0–1), Last Mountain (0–2), Madge (2), Margo (0–2), Sandy Beach (2), Stony (3), Wabeno (2), Waskesiu (0–2).

Chroococcus turgidus (Kütz.) Näg. (30, p. 31, Pl. 1, Fig. 9; 11, p. 77, Fig. 71).

Birch (3–1), Fishing (0–1), Last Mountain (0–1), Pelletier (2), Round II (1), Stony (2), Waskesiu (0–2).

Aphanocapsa delicatissima W. and G. S. West (30, p. 41, Pl. 2, Fig. 7; 11, p. 65, Fig. 54).

Big Quill (0–2), Bitter (2), Good Spirit (1), Jackfish (0–1), Kenderdine (0–2), Last Mountain (0–3), Little Quill (2–3), Murray (0–1), Waskesiu (0–3), Wilson (2).

Aphanocapsa elachista var. **conferta** W. and G. S. West (30, p. 42, Pl. 2, Fig. 3; 11, p. 65, Fig. 56; 10, p. 21, Fig. 21).

Birch (0–1), Christopher (1), Clearwater (3), Crean (0–1), Echo (0–2), Good Spirit (2), Greenwater (0–2), Halkett (0–2), Helene (1), Jackfish (1–2), Kenderdine (1–4), Lenore (2), Madge (2), Midnight (2), Moose Creek (1), Murray (0–1), Pelletier (1), Redberry (0–2), Round I (2), Stoney (1), Stony (3), Tibiska (2), Turtle (1–2), Wabeno (2), Waskesiu (0–3).

Aphanocapsa Grevillei (Hass.) Rab. (30, p. 43, Pl. 3, Fig. 1; 11, p. 65, Fig. 57).

Antelope (0–2), Bagwa (2), Birch (2–3), Halkett (0–2), Madge (2), Stony (2), Tibiska (2), Waskesiu (0–3).

Aphanocapsa pulchra (Kütz.) Rab. (30, p. 42, Pl. 2, Fig. 9; 11, p. 65, Fig. 53).

Birch (2), Broughton (2), Christopher (2), Crean (0–2), Echo (0–1), Edwards (1), Emma (2), Fishing (1), Greenwater (2–3), Jackfish (0–1), Kenderdine (1–2), Kingsmere (0–1), Last Mountain (0–3), Lavallee (2), Little Loon (2), Little Quill (0–1), Madge (2), Margo (2), Meeting (1), Midnight (2), Moose Creek (2), Murray (0–4), Pasqua (2), Pelletier (1), Round I (2), Round II (3), Stony (3), Sturgeon (2), Tibiska (1), Turtle (0–2), Wakaw (2), Waskesiu (0–2), Wilson (1).

Aphanocapsa rivularis (Carm.) Rab. (30, p. 43, Pl. 3, Fig. 2; 11, p. 66, Fig. 58).

Echo (0–3), Greenwater (0–1), Meeting (1), Murray (0–1), Waskesiu (0–1).

Microcystis aeruginosa Kütz. (30, p. 39, Pl. 5, Figs. 2, 3; 11, p. 58, Figs. 37, 40).

Bagwa (1), Birch (2–3), Broughton (3), Christopher (2), Echo (1–3), Edwards (1), Emma (3), Fishing (2), Good Spirit (2), Greenwater (1–3), Helene (1), Jackfish (0–2), Kenderdine (2–3), Last Mountain (2–3), Lenore (1), Little Loon (3), Madge (2), Margo (3), Meeting (2), Midnight (2), Moose Creek (2), Murray (2–4), Pasqua (2), Pelletier (2), Round I (1), Round II (2), Shady (3), Stoney (2), Stony (3), Sturgeon (3), Turtle (2), Wakaw (2), Waskesiu (0–3), Waskesiu Narrows (3), Witchekan (1).

Microcystis aeruginosa var. **major** (Wittr.) G. M. Smith (30, p. 40, Pl. 4, Fig. 6; 11, p. 60).

Birch (2–3), Broughton (1), Echo (1–4), Fishing (1), Jackfish (0–3), Kenderdine (2), Moose Creek (2), Murray (0–2), Round II (2), Sturgeon (2), Wakaw (2), Waskesiu (0–2), Wilson (1).

Microcystis flos-aquae (Wittr.) Kirchner (30, p. 39, Pl. 5, Fig. 1; 11, p. 60, Figs. 41, 42).

Birch (1–2), Broughton (2), Echo (0–2), Emma (2), Fishing (1–2), Greenwater (0–3), Halkett (0–1), Helene (1), Jackfish (0–1), Kenderdine (0–2), Last Mountain (0–1), Lavallee (1), Lenore (2), Madge (1), Margo (1), Meeting (2), Murray (0–3), Pasqua (2), Redberry (0–1), Shady (1), Stony (3), Sturgeon (1), Turtle (2), Waskesiu (0–2), Waskesiu Narrows (2).

Microcystis pulvera (Wood) Migula (30, p. 40; 11, p. 62).

Birch (1–2), Emma (1), Fishing (0–1), Kenderdine (0–1), Midnight (1), Murray (0–1), Pasqua (1), Stony (2), Turtle (0–2), Waskesiu (0–1).

Microcystis pulvera var. **incerta** (Lemm.) Crow (= *M. incerta* Lemm.) (30, p. 40, Pl. 5, Fig. 4; 11, p. 65, Fig. 47; 10, p. 20).

Birch (0–2), Echo (0–1).

Mycrocystis viridis (A. Br.) Lemm. (11, p. 58; 10, p. 18, Fig. 13).

Bagwa (1), Shady (1), Wilson (1).

Merismopedia elegans A. Br. (30, p. 32, Pl. 2, Fig. 5; 11, p. 107, Fig. 126; 10, p. 13, Fig. 11).

Atten (1), Bitter (1), Broughton (1), Halkett (0–1), Margo (0–1), Murray (0–1), Round II (1), Wakaw (1).

Merismopedia glauca (Ehr.) Näg. (30, p. 32, Pl. 2, Fig. 4; 11, p. 106, Fig. 125).

Basin (1), Bitter (1), Broughton (1), Echo (0–1), Kenderdine (0–2), Kingsmere (0–1), Last Mountain (0–3), Margo (0–1), Pasqua (1), Shady (1), Turtle (0–1), Wakaw (1), Witchekan (1).

Merismopedia punctata Meyen (30, p. 33, Pl. 2, Fig. 3; 11, p. 106, Fig. 124).

Atten (1), Basin (1), Big Quill (0–2), Clearwater (1), Fishing (0–1), Greenwater (0–2), Halkett (0–1), Last Mountain (0–1), Lenore (1), Meeting (1), Turtle (0–1), Wakaw (1), Waskesiu (0–1), Wilson (1).

Merismopedia tenuissima Lemm. (30, p. 33, Pl. 2, Fig. 2; 11, p. 106, Fig. 123).

Big Quill (0–1), Birch (0–1), Broughton (2), Christopher (2), Emma (1), Helene (1), Kenderdine (0–2), Midnight (1), Murray (0–1), Redberry (0–1), Shady (1), Stoney (1), Stony (2), Sturgeon (2), Turtle (1–2), Waskesiu (0–1), Witchekan (2).

Holopedia irregularis Lagerh. (11, p. 109; 10, p. 16; 13, p. 162, Fig. 59A).

Lenore (1), Murray (0–1), Pasqua (1), Witchekan (1).

Aphanothece stagnina (Spreng.) A. Br. (30, p. 45, Pl. 6, Fig. 2; 11, p. 70, Fig. 65).

Bagwa (1), Waskesiu (0–2).

Coelosphaerium dubium Grunow (30, p. 35, Pl. 3, Fig. 7; 11, p. 102, Fig. 118).

Antelope (0–1), Birch (0–2), Christopher (1), Murray (0–1).

Coelosphaerium Kuetzingianum Näg. (30, p. 34, Pl. 3, Figs. 4, 5; 11, p. 102, Figs. 116, 117).

Fishing (0–1), Last Mountain (0–1), Meeting (1), Stoney (1), Stony (1), Turtle (0–1), Waskesiu (0–2), Waskesiu Narrows (1), Wilson (1).

Coelosphaerium Naegelianum Unger (30, p. 35, Pl. 3, Fig. 6, Pl. 4, Fig. 1; 11, p. 101, Fig. 115).

Antelope (4), Basin (1), Birch (3–4), Carlyle (1), Clearwater (1), Echo (0–3), Emma (2), Fishing (0–2), Good Spirit (2), Greenwater (0–1), Helene (2), Jackfish (0–3), Kenderdine (2), Kingsmere (0–1), Last Mountain (2–3), Lavallee (2), Lenore (1), Little Loon (3), Little Quill (0–1), Margo (0–3), Meeting (2), Moose Creek (2), Murray (0–2), Pelletier (1), Redberry (0–1), Round I (3), Shady (2), Stoney (1), Stony (3), Sturgeon (3), Tibiska (2), Turtle (2), Wakaw (1), Waskesiu (0–3), Waskesiu Narrows (3), Wilson (1).

Gomphosphaeria aponina Kütz. (30, p. 37, Pl. 4, Figs. 2, 3; 11, p. 98, Figs. 108, 109, 112, 113).

Antelope (2), Big Quill (0–1), Birch (3–4), Bitter (1), Broughton (3), Christopher (1), Clearwater (1), Echo (0–1), Emma (2), Fishing (0–2), Halkett (0–2), Helene (1), Jackfish (2–3), Kenderdine (0–3), Last Mountain (0–3), Margo (0–3), Meeting (1), Midnight (2), Murray (0–2), Redberry (0–3), Stony (3), Sturgeon (1), Turtle (0–1), Waskesiu (0–1).

Gomphosphaeria aponina var. **cordiformis** Wolle (30, p. 37, Pl. 4, Fig. 4; 11, p. 98, Fig. 111).

Birch (1–2).

Gomphosphaeria lacustris Chod. (30, p. 36, Pl. 4, Fig. 5; 11, p. 98, Fig. 110, 114).

Birch (1), Good Spirit (1), Greenwater (0–1), Kenderdine (1–2), Lenore (3), Little Quill (1–2), Meeting (1), Pelletier (2), Round I (2), Wilson (1).

Tetrapedia Reinschiana Archer (10, p. 10, Fig. 6; 11, p. 118, Fig. 154).

Birch (0–1), Broughton (1), Clearwater (3), Crean (0–1), Fishing (0–1), Halkett (0–1), Kenderdine (0–2), Lenore (3), Madge (1), Midnight (1), Redberry (0–1), Stony (1), Turtle (0–1), Waskesiu (0–1).

OSCILLATORIACEAE

Spirulina major Kütz. (30, p. 50, Pl. 7, Fig. 1; 11, p. 347, Fig. 412).

Kenderdine (0–1), Last Mountain (0–2), Lenore (1), Little Quill (0–1), Manito (0–1), Margo (0–1), Murray (0–1).

Spirulina princeps W. and G. S. West (30, p. 50, Pl. 7, Fig. 2; 11, p. 348, Fig. 414).

Little Quill (0–1).

Oscillatoria limosa Ag. (11, p. 357, Fig. 420; 10, p. 212, Fig. 178).

Basin (1), Jackfish (0–2), Wilson (2).

Oscillatoria prolifica (Greville) Gomont (30, p. 51, Pl. 7, Figs. 3 to 5; 11, p. 369, Fig. 448).

Kingsmere (0–1), Last Mountain (0–1).

Oscillatoria tenuis Ag. (30, p. 52, Pl. 7, Fig. 6; 11, p. 362, Fig. 427, 428*a*).

Basin (1), Kenderdine (0–1), Little Quill (0–1), Margo (0–1), Wakaw (1), Waskesiu (0–1).

Trichodesmium lacustre Klebahn (30, p. 54, Pl. 8, Fig. 1; 11, p. 362, Fig. 436).

Meeting (1), Pelletier (1), Witchekan (1).

Lyngbya Birgei G. M. Smith (30, p. 54, Pl. 7, Figs. 14, 15; 11, p. 401, Fig. 505).

Bagwa (3), Birch (3), Broughton (2), Christopher (2), Crean (0–2), Echo (0–4), Edwards (1), Emma (1), Fishing (3), Greenwater (2), Halkett (2–4), Helene (2), Jackfish (1–2), Kingsmere (0–1), Last Mountain (0–2), Lavallee (1), Little Loon (4), Little Manitou (0–2), Madge (3), Margo (2–3), Meeting (3), Murray (0–3), Pasqua (1), Redberry (0–2), Round I (1), Round II (1), Shady (1), Stony (1), Sturgeon (2), Turtle (2–3), Wabeno (4), Wakaw (1), Waskesiu (0–1), Witchekan (1).

Lyngbya Birgei var. **minor** var. nov.

Atten (1), Basin (1), Big Quill (0–3), Last Mountain (0–1), Little Manitou (0–1), Little Quill (0–3), Margo (0–3), Murray (0–2), Sturgeon (2).

The specimens differ from the typical *L. Birgei* only in the smaller width of the cells. They measured 13 to 16.5 μ in diameter. This may perhaps be thought an effect of high salinity; but in several lakes the smaller forms were found together with filaments having cells 18 to 20 μ in diameter. Until further collections show that the minimal limits of *L. Birgei* should be lowered so as to include these smaller specimens, they are proposed as a new variety of this species.

Lyngbya Birgei var. *minor* var. nov. Differt a forma typica tantum dimensione cellulae. Cellulis 13–16.5 μ latis.

Lygnbya contorta Lemm. (30, p. 53, Pl. 7, Figs. 12, 13; 11, p. 397, Fig. 501).

Basin (2), Big Quill (3–4), Bitter (2), Good Spirit (1), Last Mountain (0–2), Midnight (1), Pasqua (1), Wilson (3).

Lyngbya limnetica Lemm. (30, p. 52, Pl. 7, Figs. 9 to 11; 11, p. 399, Fig. 504).

Broughton (2), Crean (0–4), Fishing (0–2), Good Spirit (3), Halkett (0–3), Helene (2), Jackfish (0–2), Kenderdine (0–2), Kingsmere (0–3), Margo (0–2), Midnight (2), Redberry (0–1), Shady (1), Stony (3), Turtle (0–2), Waskesiu (0–4), Witchekan (2).

Lyngbya putealis Mont. (11, p. 405, Fig. 517; 10, p. 193, Fig. 159).

Broughton (1). A single filament, probably introduced by migratory birds.

NOSTOCACEAE

Anabaena affinis Lemm. (30, p. 57, Pl. 8, Fig. 7; 11, p. 320, Fig. 374).

Kingsmere (0–2), Moose Creek (2), Waskesiu (0–1).

Anabaena circinalis (Kütz.) Rab. (30. p. 59, Pl. 9, Figs. 4, 5).

Bagwa (2), Crean (0–2), Halkett (0–2), Kingsmere (0–1), Last Mountain (0–2), Moose Creek (2), Waskesiu (0–3).

Anabaena flos-aquae (Lyngb.) Bréb. (30, p. 60, Pl. 10, Figs. 2 to 4; 11, p. 322, Fig. 379).

Bagwa (2), Birch (1–3), Brightsand (1–2), Christopher (2), Echo (0–3), Emma (2), Fishing (2–3), Greenwater (3–4), Halkett (0–3), Jackfish (0–3), Kenderdine (0–3), Kenosee (3), Kingsmere (0–3), Last Mountain (0–4), Lavallee (2), Little Loon (3), Madge (2), Margo (0–2), Meeting (2), Murray (2–5), Pasqua (2), Shady (3), Stony (1), Sturgeon (3), Turtle (1–2), Wabeno (3), Waskesiu (0–3), Wilson (2).

Anabaena Lemmermanni P. Richter (30, p. 61, Pl. 10, Fig. 8, Pl. 11, Fig. 1; 11, p. 322, Fig. 391).

Bagwa (2), Crean (0–1), Emma (2), Good Spirit (1), Greenwater (0–3), Halkett (2–4), Jackfish (0–2), Kingsmere (0–3), Last Mountain (0–3), Lavallee (2), Little Loon (2), Madge (2), Meeting (1), Moose Creek (4), Murray (0–3), Round I (3), Shady (2), Tibiska (3), Waskesiu (0–4), Waskesiu Narrows (2).

Frequently spore masses only were found.

Anabaena limnetica G. M. Smith (30, p. 57, Pl. 8, Fig. 8; 11, p. 316, Fig. 367).

Bagwa (2), Crean (0–1), Kingsmere (0–2), Lavallee (2), Shady (2), Tibiska (2), Waskesiu (0–2).

Anabaena macrospora var. **robusta** Lemm. (30, p. 57, Pl. 8, Fig. 6; 11, p. 322, Fig. 378).
Waskesiu Narrows (3).

Anabaena spiroides Klebahn (11, p. 325; 10, p. 361, Fig. 296).

Bagwa (3), Greenwater (0–2), Halkett (0–1), Moose Creek (3), Pasqua (2), Round I (2), Shady (2), Tibiska (2), Waskesiu (0–3), Waskesiu Narrows (4).

To the Saskatchewan specimens apply the remarks of Moore and Carter (20), "The specimens were almost exactly similar to Klebahn's examples, the only difference being in the slightly smaller size of the spirals, which were about 30–40 μ in diameter, and the turns 30–40 μ apart, instead of 45–54 μ in the first case and 40–50 μ in the second as given by Klebahn".

Anabaena spiroides var. **crassa** Lemm. (30, p. 59, Pl. 9, Figs. 1 to 3; 11, p. 325, Fig. 383).
Echo (0–2).

Nostoc Linckia (Roth) Born. (11, p. 298, Fig. 346; 10, p. 332, Fig. 276).

Waskesiu (0–1). In floating debris.

Aphanizomenon flos-aquae (L.) Ralfs (30, p. 61, Pl. 11, Figs. 2 to 4; 11, p. 290, Fig. 342).

Bagwa (3), Crean (0–1), Deep (2), Echo (0–4), Fishing (1), Greenwater (3), Kenosee (4), Kingsmere (0–2), Moose Creek (1), Murray (0–1), Pasqua (3), Round I (1), Shady (4), Sturgeon (3), Tibiska (2), Wakaw (3), Waskesiu (0–4), Waskesiu Narrows (4), Witchekan (1).

Nodularia spumigena Mertens (11, p. 289; 13, p. 200, Fig. 107).

Antelope (0–4), Fishing (0–1), Greenwater (0–1), Kenderdine (1–3), Little Quill (2–3), Redberry (0–3), Round I (1).

Moore (19) reported this species from Devil's Lake, North Dakota. Smith (32), commenting on this report, asserts, "Its occurrence as the most abundant and widely distributed of the Myxophyceae in the plankton of the lakes in North Dakota is most surprising, since not a single filament has been recorded from plankton surveys involving hundreds of lakes in other parts of the United States or in Great Britain". The Saskatchewan specimens were found only in saline lakes, the variety *major* being restricted to those with greater concen tration of salts. That *N. spumigena* and its varieties float freely may be an effect of salinity and does not seem to be of rare occurrence. Lakowitz (16) records them as such from the coasts of Europe and North America and from saline lakes of continental Europe.

Nodularia spumigena var. **major** (Kütz.) Born. and Flah. (13, p. 201; 33, p. 185).
Antelope (0–3), Big Quill (0–1), Manito (1–4).

STIGONEMATACEAE

Stigonema hormoides (Kütz.) Born. and Flah. (11, p. 183, Fig. 219; 10, p. 397, Fig. 325).
Round II (1). Only fragments. Doubtful.

RIVULARIACEAE

Gloeotrichia echinulata (J. E. Smith) P. Richter (30, p. 63, Pl. 11, Figs. 5, 6; 11, p. 236, Fig. 285).

Carlyle (2), Edwards (1), Fishing (0–1), Good Spirit (1), Greenwater (3–4), Halkett (0–1), Kenosee (1), Lavallee (1), Madge (1), Margo (1–5), Meeting (1), Murray (0–1), Sturgeon (1).

CHLOROPHYCEAE

The green algae are represented by a greater number of species and varieties than any other phytoplankton group, though in actual quantity they never form the dominant member of the community. The commonest genera are *Dictyosphaerium*, *Pediastrum*, *Scenedesmus*, *Sphaerocystis*, *Staurastrum*, and *Tetraëdron*. The hardness of the water might account for the scarcity of the desmids. *Volvox mononae* was found only in Shady Lake as a common, and even abundant, constituent of a bloom. The green algae, as a whole, were more numerous and frequent in the freshwater lakes and those of low salinity. Most saline lakes have no outlet and their salinity is gradually increasing. Little Quill Lake, for instance, had a total solid content of 10,850 p.p.m. in 1920 (14). This had risen to 19,368 p.p.m. in 1938 (21), an increase of nearly 80% in 18 years. It is probable that most green algae are unable to adapt themselves to the increasing concentration of salts and disappear from the lakes. Several species of *Lagerheimia*, *Oocystis*, *Scenedesmus*, and *Sphaerocystis*, however, maintain themselves even in very high concentrations.

VOLVOCACEAE

Pandorina morum Bory (30, p. 95, Pl. 16, Figs. 16, 17; 25, p. 427, Figs. 387 to 389; 26, p.10, Pl. 2, Fig. 3).
Echo (0–1), Little Loon (1), Shady (1), Waskesiu (0–2).

Eudorina elegans Ehr. (30, p. 96, Pl. 19, Fig. 1; 25, p. 440, Figs. 394 to 401; 26, p. 9, Pl. 2, Fig. 2).
Greenwater (0–2).

Volvox mononae G. M. Smith (30, p. 99, Pl. 18, Fig. 1; 26, p. 12, Pl. 3, Fig. 2).
Shady (4).

PALMELLACEAE

Sphaerocystis Schroeteri Chod. (30, p. 101, Pl. 19, Figs. 3, 4).
Antelope (0–2), Atten (1), Beartrap Creek (1), Birch (0–2), Christopher (3), Clearwater (1), Crean (0–1), Echo (0–2), Emma (1), Greenwater (0–2), Halkett (1–3), Jackfish (0–2), Kenderdine (0–2), Kingsmere (0–2), Last Mountain (0–2), Little Loon (1), Margo (0–2), Meeting (1), Murray (0–2), Round I (2), Shady (1), Tibiska (1), Turtle (1), Wabeno (1), Waskesiu (0–3).

Gloeocystis gigas (Kütz.) Lagerh. (30, p. 101, Pl 19, Fig. 2).
Brightsand (0–1), Crean (0–1), Little Quill (0–2), Pelletier (1), Waskesiu (0–1).

Asterococcus limneticus G. M. Smith (30, p. 104, Pl. 20, Figs. 7 to 10).
Halkett (0–1).

CHLORANGIACEAE

Stylosphaeridium stipitatum (Bachm.) Geitler and Gimesi (32, p. 364, Fig. 244; 25, p. 482, Figs. 437, 438). Found only on *Coelosphaerium Naegelianum*.
Antelope (0–1), Birch (0–1), Margo (0–1), Shady (1), Tibiska (1), Waskesiu (0–1).

COCCOMYXACEAE

Elaktothrix gelatinosa Wille (30, p. 139, Pl. 34, Figs. 1 to 3; 8, p. 41, Pl. 2, Fig. 14).
Birch (0–1), Kenderdine (0–1).

ULOTRICHACEAE

Ulothrix subconstricta G. S. West (30, p. 179, Pl. 50, Figs. 4, 5).
Christopher (1), Greenwater (0–2), Pasqua (1), Redberry (0–1).

Ulothrix zonata (Web. and Mohr) Kütz. (30, p. 179, Pl. 50, Fig. 6; 7, p. 185, Pl. 6, Fig. 64).
Kingsmere (0–1).

CLADOPHORACEAE

Cladophora crispata (Roth) Kütz. (12, p. 40, Fig. 40; 7, p. 354).
Basin (2), Big Quill (0–2).

Cladophora fracta (Dillw.) Kütz. (12, p. 42, Figs. 41 to 44; 7, p. 353).
Beartrap Creek (3), Echo (0–1), Last Mountain (0–2).

Cladophora glomerata (L.) Kütz. (12, p. 35, Figs. 14, 15, 39; 7, p. 351, as *C. canalicularis*).
Little Manitou (0–3), Manito (0–2).

OEDOGONIACEAE

Oedogonium sp.
Little Manitou (1–4). Specimens were found in all collections and, at times, abundantly; all filaments, however, were sterile. The high salinity, about three times that of the ocean, probably causes the form to reproduce only vegetatively. Cells were 12 to 30 μ in width, 45 to 105 μ in length.

ULVACEAE

Enteromorpha prolifera var. **tubulosa** (Kütz.) Reinbold (7, p. 203).
Basin (1), Little Manitou (0–3), Manito (0–3).

CHLOROCOCCACEAE

Golenkinia paucispina W. and G. S. West (30, p. 127, Pl. 29, Figs. 4, 5).
Last Mountain (0–1).

Golenkinia radiata Chod. (30, p. 127, Pl. 29, Figs. 2, 3).
Clearwater (1), Last Mountain (0–1).

CHARACIACEAE

Characium gracilipes Lambert (30, p. 178, Pl. 49, Figs. 20 to 24; 7, p. 151, Pl. 5, Fig. 36).
Kingsmere (0–1).

HYDRODICTYACEAE

Pediastrum biradiatum Meyen (30, p. 173, Pl. 48, Figs. 5 to 8; 7, p. 179).
Waskesiu (0–1).

Pediastrum Boryanum (Turp.) Menegh. (30, p. 169, Pl. 46, Figs. 2 to 7; 7, p. 177).
Antelope (0–1), Atten (1), Basin (2), Beartrap Creek (1), Big Quill (0–2), Birch (3), Brightsand (2), Broughton (2), Christopher (2), Crean (0–2), Deep (1), Echo (0–2), Emma (3), Fishing (0–3), Good Spirit (1), Greenwater (0–2), Halkett (1–2), Helene (3), Jackfish (1–3), Kenderdine (0–3), Last Mountain (1–3), Lavallee (2), Lenore (1), Little Loon (3), Little Manitou (0–1), Little Quill (1–3), Manito (0–1), Margo (0–3), Meeting (3), Midnight (3), Moose Creek (1), Pasqua (2), Pelletier (1), Redberry (0–2), Round II (2), Sandy Beach (1), Shady (1), Soda (0–2), Stony (3), Sturgeon (2), Tibiska (1), Turtle (2–3), Wabeno (2), Wakaw (1), Waskesiu (0–3), Wilson (1), Witchekan (2).

Pediastrum Boryanum var. **undulatum** Wille (30, p. 170, Pl. 46, Fig. 8; 7, p. 178).
Waskesiu (0–1).

Pediastrum duplex Meyen (30, p. 171, Pl. 46, Figs. 14 to 16; 7, p. 179).
Big Quill (0–1), Birch (0–1), Broughton (1), Carlyle (1), Christopher (1), Crean (0–1), Echo (0–2), Helene (2), Jackfish (0–2), Kenderdine (0–1), Kingsmere (0–1), Last Mountain (0–3), Little Manitou (0–1), Margo (0–2), Meeting (2), Moose Creek (1), Murray (0–1), Pasqua (1), Redberry (0–1), Round I (1), Stony (1), Turtle (2–3), Waskesiu (0–2).

Pediastrum duplex var. **clathratum** (A. Br.) Lagerh. (30, p. 171, Pl. 47, Figs. 1 to 3; 7, p. 179).
Broughton (2), Echo (0–2), Helene (2), Kenderdine (0–1), Kingsmere (0–1), Last Mountain (0–2), Lavallee (1), Margo (0–1), Meeting (2), Murray (0–2), Redberry (0–1), Waskesiu (0–2).

Pediastrum duplex var. **gracillimum** W. and G. S. West (30, p. 172, Pl. 47, Figs. 8 to 11; 8, p. 54).
Broughton (1), Jackfish (0–1), Last Mountain (0–2), Murray (0–1), Waskesiu (0–1), Witchekan (2).

Pediastrum integrum Näg. (30, p. 168, Pl. 45, Fig. 7; 8, p. 54).
Christopher (1), Kingsmere (0–1), Little Quill (1), Waskesiu (0–1).

Pediastrum Kawraiskyi Schmidle (30, p. 170, Pl. 46, Figs. 10 to 13; 8, p. 54).
Brightsand (0–3), Helene (2), Meeting (2), Redberry (0–1), Stony (3), Turtle (0–1), Waskesiu (0–1), Witchekan (3).

Pediastrum simplex (Meyen) Lemm. (27, p. 56, Pl. 10, Figs. 10, 11; 7, p. 177).
Waskesiu (0–1).

Pediastrum simplex var. **duodenarium** (Bailey) Rab. (30, p. 167, Pl. 45, Figs. 2 to 6).
Birch (0–1), Redberry (0–1), Waskesiu (0–1), Witchekan (1).

Pediastrum tetras (Ehr.) Ralfs (30, p. 173, Pl. 48, Figs. 9 to 12; 7, p. 179).
Midnight (1), Stony (1), Turtle (0–1).

Sorastrum americanum var. **undulatum** G. M. Smith (30, p. 163, Pl. 44, Figs. 2, 3).
Good Spirit (1), Lavallee (1), Waskesiu (0–1).

Sorastrum spinulosum Näg. (30, p. 163, Pl. 44, Figs. 4, 5).
Big Quill (0–1), Good Spirit (1), Halkett (0–1), Jackfish (0–1), Last Mountain (0–1), Little Quill (0–2), Midnight (2), Redberry (0–2), Waskesiu (0–1).

COELASTRACEAE

Coelastrum microporum Näg. (30, p. 160, Pl. 41, Figs. 12, 13, Pl. 42, Fig. 1).
Helene (1), Last Mountain (0–1), Murray (0–1), Round I (2), Wabeno (1), Waskesiu (0–2).

OOCYSTACEAE

Chlorella vulgaris Beyerinck (30, p. 108, Pl. 22, Fig. 1).
Jackfish (0–1).

Westella botryoides (W. West) de Wildm. (30, p. 107, Pl. 21, Fig. 4; 8, p. 52, Pl. 2, Fig. 17).
Jackfish (0–2), Lenore (2), Madge (1), Waskęsiu (0–1).

Dictyosphaerium pulchellum Wood (30, p. 105, Pl. 20, Fig. 13, Pl. 21, Fig. 1).
Birch (1), Crean (0–1), Emma (1), Halkett (0–1), Jackfish (0–2), Kenderdine (1), Kingsmere (0–1), Last Mountain (0–2), Lavallee (3), Madge (1), Meeting (1), Moose Creek (1), Murray (0–1), Pasqua (1), Pelletier (2), Stony (2), Tibiska (1), Turtle (0–2), Waskesiu (0–3), Wilson (1), Witchekan (1).

Trochiscia reticularis (Reinsch) Hansg. (30, p. 109, Pl. 22, Fig. 2; 7, p. 145, Pl. 4, Fig. 32).
Good Spirit (1), Halkett (0–1).

Planktosphaeria gelatinosa G. M. Smith (30, p. 103, Pl. 20, Figs. 3 to 6).
Waskesiu (0–2).

Oocystis Borgei Snow (30, p. 111, Pl. 22, Fig. 4).
Antelope (0–1), Birch (2–3), Echo (0–1), Fishing (0–1), Halkett (0–1), Last Mountain (0–2), Margo (2–3), Redberry (0–2), Tibiska (1), Turtle (0–1), Waskesiu (0–1).

Oocystis crassa Wittr. (30, p. 113, Pl. 22, Figs. 12, 13).
Jackfish (0–2), Last Mountain (0–1), Lenore (1), Manito (0–3), Margo (0–1).

Oocystis elliptica W. West (30, p. 111, Pl. 22, Fig. 5).
Last Mountain (0–2), Stony (2).

Oocystis eremosphaeria G. M. Smith (30, p. 113, Pl. 23, Figs. 1, 2).
Echo (0–2).

Oocystis lacustris Chod. (30, p. 112, Pl. 22, Figs. 8, 9).
Antelope (0–1), Birch (2–3), Echo (0–2), Helene (2), Jackfish (0–1), Kenderdine (0–2), Kenosee (1), Lenore (3), Little Quill (0–2), Madge (1), Margo (0–2), Meeting (1), Murray (0–1), Pasqua (1), Stoney (1), Waskesiu (0–1), Wilson (1).

Oocystis parva W. and G. S. West (30, p. 112, Pl. 22, Fig. 3).
Helene (2), Meeting (1), Murray (0–1), Waskesiu (0–1).

Oocystis pusilla Hansg. (30, p. 111, Pl. 22, Fig. 3).
Kenderdine (0–3), Waskesiu (0–1), Witchekan (2).

Oocystis solitaria Wittr. (30, p. 113, Pl. 22, Fig. 11).
Echo (0–2), Jackfish (0–2).

Lagerheimia ciliata (Lagerh.) Chod. (30, p. 129, Pl. 31, Figs. 1, 2).
Pelletier (2), Waskesiu (0–1).

Lagerheimia Droescheri (Lemm.) Printz (30, p. 131, Pl. 30, Figs. 5 to 7).
Basin (1), Fishing (0–1), Kenderdine (0–1).

Lagerheimia longiseta (Lemm.) Printz (30, p. 130, Pl. 30, Figs. 8, 9).
Redberry (0–1).

Lagerheimia subsalsa Lemm. (30, p. 130, Pl. 30, Figs. 3, 4).
Basin (1), Clearwater (1), Kenderdine (0–1).

Dimorphococcus lunatus A. Br. (30, p. 106, Pl. 21, Fig. 5).
Jackfish (0–1), Lenore (1), Pelletier (1), Redberry (0–1).

Ankistrodesmus spiralis (Turner) Lemm. (30, p. 135, Pl. 32, Figs. 6, 7).
Clearwater (1), Halkett (0–1), Jackfish (0–1), Kenderdine (0–1), Last Mountain (0–1), Moose Creek (1).

Selenastrum gracile Reinsch (30, p. 133, Pl. 31, Fig. 5).
Waskesiu (0–2).

Selenastrum Westii G. M. Smith (30, p. 133, Pl. 31, Figs. 8 to 10).
Brightsand (0–2), Witchekan (1).

Kirchneriella lunaris var. **Dianae** Bohl. (30, p. 141, Pl. 34, Fig. 5).
Waskesiu (0–1).

Kirchneriella obesa (W. West) Schmidle (30, p. 142, Pl. 35, Figs. 2, 3).
Manito (0–2), Stony (2), Waskesiu (0–1).

Tetraëdron caudatum (Corda) Hansg. (30, p. 120, Pl. 25, Figs. 4 to 7).
Kenderdine (0–1), Midnight (1), Turtle (0–1), Witchekan (1).

Tetraëdron hastatum var. **palatinum** (Schmidle) Lemm. (30, p. 121, Pl. 25, Figs. 19 to 21).
Waskesiu (0–1).

Tetraëdron limneticum Borge (30, p. 123, Pl. 27, Figs. 1 to 3).
Waskesiu (0–2).

Tetraëdron trigonum var. **gracile** (Reinsch) de Toni (30, p. 117, Pl. 24, Figs. 5 to 9).
Waskesiu (0–1).

Tetraëdron trigonum var. **minor** Reinsch (27, p. 68, Pl. 14, Figs. 39, 40).
Clearwater (3), Fishing (0–1), Lenore (2).

SCENEDESMACEAE

Scenedesmus arcuatus Lemm. (30, p. 153, Pl. 38, Figs. 12 to 14).
Birch (0–2), Brightsand (0–1), Fishing (0–1), Helene (2), Kenderdine (0–1), Meeting (1), Midnight (2), Turtle (0–1).

Scenedesmus bijuga (Turp.) Lagerh. (30, p. 152, Pl. 37, Figs. 18 to 20).
Brightsand (0–1), Christopher (1), Clearwater (2), Halkett (0–1), Helene (3), Jackfish (0–1), Kenderdine (0–3), Last Mountain (0–1), Lenore (2), Margo (0–1), Meeting (1), Midnight (2), Pasqua (1), Pelletier (1), Stony (2), Tibiska (1), Waskesiu (0–1), Wilson (2), Witchekan (2).

Scenedesmus bijuga var. **alternans** (Reinsch) Borge (30, p. 153, Pl. 38, Figs. 10, 11).
Kenderdine (0–1), Lenore (1).

Scenedesmus dimorphus (Turp.) Kütz. (30, p. 151, Pl. 37, Figs. 15 to 17).
Kenderdine (0–1).

Scenedesmus obliquus (Turp.) Kütz. (30 p. 151, Pl. 37, Figs. 12 to 14).
Fishing (0–1), Wakaw (1), Witchekan (2).

Scenedesmus quadricauda (Turp.) Bréb. (30, p. 158, Pl. 40, Figs. 9 to 11).
Basin (1), Birch (1), Broughton (2), Christopher (2), Clearwater (1), Echo (0–1), Fishing (0–3), Halkett (0–1), Helene (3), Kenderdine (0–2), Last Mountain (0–1), Lenore (2), Margo (0–2), Meeting (1), Midnight (1), Murray (0–1), Round II (1), Stoney (1), Stony (2), Turtle (2), Waskesiu (0–1).

Scenedesmus quadricauda var. **parvus** G. M. Smith (30, p. 158, Pl. 40, Fig. 17).
Broughton (2).

Scenedesmus quadricauda var. **quadrispina** (Chod.) G. M. Smith (30, p. 158, Pl. 40, Figs. 15, 16).
Lenore (2), Midnight (1), Redberry (0–1), Wilson (1).

Crucigenia irregularis Wille (30, p. 145, Pl. 36, Figs. 4, 5).
Halkett (0–2), Helene (1), Moose Creek (1), Waskesiu (0–1).

Crucigenia quadrata Morren (30, p. 147, Pl. 36, Figs. 10 to 14).
Fishing (0–1), Jackfish (0–1), Little Quill (0–3), Madge (1), Witchekan (0–3).

Crucigenia rectangularis (Näg.) Gay (30, p. 144, Pl. 36, Fig. 3).
Christopher (3), Stony (1).

Actinastrum gracillimum G. M. Smith (30, p. 164, Pl. 43, Figs. 3 to 5).
Waskesiu (0–1).

DESMIDIACEAE

Closterium acerosum (Schrank) Ehr. (34, Vol. 1, p. 146, Pl. 18, Figs. 2 to 5; 31, p. 10, Pl. 53, Fig. 1).
Echo (0–1), Jackfish (0–1), Last Mountain (0–2), Margo (1), Meeting (1), Murray (0–1), Wabeno (1).

Closterium acerosum var. **elongatum** Bréb. (34, Vol. 1, p. 147, Pl. 18, Fig. 1).
Kenderdine (0–1), Pasqua (1).

Closterium aciculare T. West (31, p. 11).
Round II (3).

Closterium aciculare var. **subpronum** W. and G. S. West (34, Vol. 1, p. 175, Pl. 23, Figs. 4, 5; 31, p. 11, Pl. 53, Fig. 3).
Halkett (0–3), Jackfish (0–1), Murray (0–1), Round II (2), Soda (0–1), Waskesiu (0–1).

Closterium acutum (Lyngb.) Bréb. (34, Vol. 1, p. 177, Pl. 23, Figs. 9 to 14; 31, p. 11, Pl. 53, Fig. 4).
Halkett (0–1).

Closterium gracile var. **elongatum** W. and G. S. West. (34, Vol. 1, p. 168, Pl. 21, Figs 14 to 16; 31, p. 11, Pl. 53, Fig. 2).
Sturgeon (1), Waskesiu (0–1).

Closterium moniliferum (Bory) Ehr. (34, Vol. 1, p. 142, Pl. 16, Figs. 15, 16; 31, p. 9, Pl. 52, Fig. 10).
Beartrap Creek (1), Deep (1), Echo (0–1), Jackfish (0–1).

Closterium parvulum Näg. (34, Vol. 1, p. 133, Pl. 15, Figs. 9 to 12).
Kenderdine (0–2).

Closterium pronum Bréb. (34, Vol. 1, p. 173, Pl. 23, Figs. 1 to 3).
Edwards (1), Kenderdine (0–1).

Closterium Venus Kütz. (34, Vol. 1, p. 137, Pl. 15, Figs. 15 to 20; 31, p. 9, Pl. 52, Fig. 9).
Kingsmere (0–1).

Pleurotaenium coronatum (Bréb.) Rab. (34, Vol. 1, p. 199, Pl. 27, Figs. 16 to 18, Pl. 28, Fig. 4).
Waskesiu (0–1). Doubtful.

Pleurotaenium maximum (Reinsch) Lund. (34, Vol. 1, p. 213, Pl. 31, Figs. 1, 2).
Kingsmere (0–1).

Cosmarium asphaerosporum Nordst. (34, Vol. 2, p. 163, Pl. 60, Figs. 24, 25).
Clearwater (1).

Cosmarium cyclicum var. **Nordstedtianum** (Reinsch) W. and G. S. West (34, Vol. 2, p. 146, Pl. 58, Fig. 12; 31, p. 32, Pl. 57, Figs. 19, 20).
Fishing (0–2), Last Mountain (0–1), Meeting (2), Pasqua (1), Turtle (0–), Waskesiu (0–1).

Cosmarium depressum var. **achondrum** (Boldt) W. and G. S. West (34, Vol. 2, p. 177, Pl. 62, Figs. 6 to 9; 31, p. 30, Pl. 57, Figs. 5, 6).
Halkett (0–1), Waskesiu (0–1).

Cosmarium granatum Bréb. (34, Vol. 2, p. 186, Pl. 63, Figs. 1 to 3).
Lenore (3).

Cosmarium laeve var. **septentrionale** Wille (34, Vol. 3, p. 102, Pl. 73, Figs. 22 to 25).
Turtle (0–1).

Cosmarium margaritiferum Menegh. (34, Vol. 3, p. 199, Pl. 83, Figs. 4 to 11).
Echo (0–1), Kenderdine (0–1).

Cosmarium Meneghinii Bréb. (34, Vol. 3, p. 90, Pl. 72, Figs. 29 to 32).
Clearwater (1), Kenderdine (0–1), Madge (2), Soda (0–1), Turtle (1).

Cosmarium punctulatum var. **subpunctulatum** (Nordst.) Börg. (34, Vol. 3, p. 209, Pl. 84, Figs. 15 to 20).
Kenderdine (0–1).

Cosmarium reniforme (Ralfs) Archer (34, Vol. 3, p. 157, Pl. 79, Figs. 1, 2, Pl. 82, Fig. 15; 31, p. 33, Pl. 57, Fig. 23).
Echo (0–1).

Cosmarium subtumidium var. **Klebsii** (Gutw.) W. and G. S. West (34, Vol. 2, p. 193, Pl. 63, Figs. 21 to 23).
Halkett (0–1), Tibiska (1), Turtle (0–1), Wabeno (1).

Cosmarium tenue Archer (34, Vol. 2, p. 167, Pl. 61, Figs. 12 to 15).
Kenderdine (0–1), Lenore (2), Turtle (0–1), Wilson (1), Witchekan (1).

Staurastrum anatinum Cooke and Wills (34, Vol. 5, p. 142, Pl. 146, Fig. 7, Pl. 147, Fig. 1).
Greenwater (0–1), Halkett (0–2), Moose Creek (1), Stony (1), Turtle (0–1), Waskesiu (0–2).

Staurastrum Chaetoceras (Schröd.) G. M. Smith (31, p. 99, Pl. 76, Figs. 21 to 24, Pl. 77, Fig. 1).
Waskesiu (0–1).

Staurastrum contortum G. M. Smith (31, p. 98, Pl. 76, Figs. 17 to 20).
Helene (1), Stony (1), Waskesiu (0–1).

Staurastrum curvatum W. West (34, Vol. 5, p. 19, Pl. 130, Figs. 15, 16; 31, p. 73, Pl. 69, Figs. 4 to 9).
Helene (1), Waskesiu (0–1).

Staurastrum cuspidatum Bréb. (34, Vol. 5, p. 23, Pl. 132, Figs. 13 to 15; 31, p. 74, Pl. 68, Figs. 27 to 34).
Waskesiu (0–1).

Staurastrum gracile Ralfs (34, Vol. 5, p. 96, Pl. 144, Figs. 3 to 7; 31, p. 88, Pl. 73, Figs. 16 to 18).
Crean (1), Greenwater (0–1), Halkett (0–2), Kenderdine (0–2), Kingsmere (0–1), Meeting (2), Murray (0–1), Waskesiu (0–1).

Staurastrum leptocladum Nordst. (31, p. 102, Pl. 78, Figs. 1 to 7).
Beartrap Creek (1), Echo (0–1), Kingsmere (0–1), Lavallee (2).

Staurastrum leptocladum var. **sinuatum** Wolle (31, p. 104, Pl. 78, Figs. 12 to 14).
Antelope (0–1).

Staurastrum longiradiatum W. and G. S. West (31, p. 90, Pl. 74, Figs. 5 to 11).
Birch (2), Broughton (1), Crean (0–2), Emma (3), Greenwater (0–2), Halkett (2–3), Jackfish (0–2), Kenderdine (0–2), Kingsmere (0–2), Margo (0–1), Meeting (3), Midnight (1), Murray (0–3), Soda (0–2), Wabeno (2), Waskesiu (0–2), Witchekan (1).

Staurastrum megacanthum Lund. (34, Vol. 5, p. 20, Pl. 131, Figs. 7, 8; 31, p. 75, Pl. 69, Figs. 16 to 21).
Turtle (0–1).

Staurastrum paradoxum Meyen (34, Vol. 5, p. 101, Pl. 145, Figs. 1 to 5; 31, p. 85, Pl. 72, Figs. 15 to 22, Pl. 73, Figs. 1, 2).
Basin (1), Big Quill (0–2), Brightsand (1–2), Broughton (2), Crean (0–2), Deep (1), Echo (0–1), Emma (2), Fishing (0–1), Greenwater (0–3), Helene (2), Jackfish (0–2), Kenderdine (0–3), Last Mountain (0–1), Margo (0–2), Meeting (3), Moose Creek (1), Pasqua (3), Pelletier (1), Redberry (0–1), Round II (1), Sandy Beach (1), Shady (1), Soda (0–1), Stony (2), Sturgeon (1), Turtle (0–2), Wabeno (2), Waskesiu (0–2).

Staurastrum paradoxum var. **longipes** Nordst. (34, Vol. 5, p. 103, Pl. 146, Figs. 2, 3; 31, p. 86, Pl. 73, Figs. 3 to 6).
Waskesiu (0–2).

Staurastrum protectum W. and G. S. West (31, p. 87).
Waskesiu (0–1).

Arthrodesmus incus (Bréb.) Hass. (34, Vol. 4, p. 90, Pl. 113, Figs. 13 to 15; 31, p. 131, Pl. 85, Figs. 19 to 22).
Waskesiu (0–1).

Spondylosium moniliforme Lund. (31, p. 141, Pl. 87, Figs. 5 to 7).
Waskesiu (0–1). Doubtful.

Hyalotheca dissiliens (Smith) Bréb. (31, p. 142, Pl. 87, Figs. 8, 9).
Last Mountain (0–1), Turtle (0–1).

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CANADIAN WILTSHIRE BACON

XXI. OBJECTIVE COLOUR COMPARISONS OF CANADIAN AND DANISH BACONS, AND THEIR RELATION TO SUBJECTIVE OBSERVATIONS OF COLOUR QUALITY[1]

BY C. A. WINKLER[2], G. ABEL[3], AND W. H. COOK[4]

Abstract

Both smoked and unsmoked Danish bacons were lighter in colour than Canadian, as determined by objective measurements with a photoelectric comparator. Little difference existed in the colour stability of the product from the two countries.

Comparison of the objective measurements with subjective estimates of colour quality indicates that for the colour comparator employed, bacons having scatter values of 30 to 36% in the red, 16 to 21% in the green, 13 to 17% in the blue and a total of 58 to 74% relative to a white standard, would be considered to have a good colour.

Introduction

The relations between colour and colour stability of Canadian Wiltshire bacon and certain aspects of curing practice, postcuring treatment, and chemical composition have been dealt with in previous communications from these laboratories (4, 5, 6, 7). In these studies a photoelectric colour comparator, described in detail elsewhere (3), was used to obtain an objective measure of colour and colour stability. Data obtained by this method, while essential and satisfactory for investigational purposes, could obviously give no information about consumer preference for colour. It was therefore impossible to assess the true significance of the numerical values used to express colour and colour stability. If, however, the objective measurements could be related to subjective observations of the consumer, a basis could be established on which to estimate the relative colour excellence of different bacons, and to determine whether or not changes in colour, from whatever cause, were to be regarded as deleterious or beneficial.

As with the flavour studies reported previously (2) a reliable consumer opinion of colour could be obtained only from representatives of the English

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[4] *Biochemist, Food Storage and Transport Investigations.*

public, since practically all the Wiltshire bacon of Canadian manufacture is consumed in England. An improved type of photoelectric colour comparator (3) was therefore taken to England at the time of the flavour investigations and used, not only to establish the relation between consumer observations and objective measurements, but also to compare the colour and colour stability of Canadian bacon with that of Danish bacon, which may be regarded as a standard of quality on the English market. The results of both these colour studies are included in the present paper.

Experimental

The materials used for the colour investigations were portions of the Danish and Canadian bacons obtained from wholesale distributors in London and submitted to the jury groups during flavour tests described previously (2). Both smoked and unsmoked bacons, taken from 10 Danish and 10 Canadian factories selected at random, were represented. With minor exceptions two sides each of smoked and unsmoked bacon were taken to represent each factory.

The method of making colour and colour stability measurements with the photoelectric comparator has been described in an earlier paper (1) and need not be discussed here.

The method of treating the data statistically has also been discussed in detail elsewhere (4, 6, 7).

The subjective observations were made by the six members of each jury group responsible for the flavour tests on corresponding samples of the same materials. Each member worked quite independently of others, and judged the colour of each sample on two successive days. The observations were in the form of comments, however, and are best treated as if the 12 comments per sample were entirely independent judgments.

Results

Objective Colour Comparisons of Canadian and Danish Bacons

Internal Colour

A complete analysis of variance is given in Table I for the colours of both smoked and unsmoked bacons. The error includes the average difference between first and second sides from the same factories (days 1 to 10 versus days 11 to 19), since these differences were not significant. From the table it is seen that a significant difference existed between the colours of unsmoked bacons of Danish and Canadian origin, but this difference between countries was not evident for the smoked product. For neither smoked nor unsmoked material was there any significant difference between factories of a given country. The means by countries for both classes of bacon over the entire test, presented in Table II, show that the Danish samples were brighter than the Canadian samples in all colour components, although as shown in Table I this difference only attains significance for the unsmoked materials.

TABLE I

INTERNAL COLOUR OF DANISH AND CANADIAN BACONS

ANALYSIS OF VARIANCE

Variance due to:	D.f.	Scatter			
		Mean square			
		Blue	Green	Red	Total
Unsmoked					
Between countries	1	25.4*	75.1**	103.0**	932.0**
Between factories (Can.)	9	5.46	9.72	17.4	88.3
Between factories (Dan.)	9	3.38	6.48	5.41	44.9
Error	19	3.73	8.05	12.2	69.3
Smoked					
Between countries	1	10.6	29.4	20.5	178.0
Between factories (Can.)	9	2.69	4.77	13.9	55.3
Between factories (Dan.)	9	3.59	7.08	14.1	65.5
Error	17	3.91	7.47	8.73	56.5

* *Indicates 5% level of significance.*
** *Indicates 1% level of significance.*

TABLE II

INTERNAL COLOUR OF DANISH AND CANADIAN BACONS

Country	Mean scatter, %			
	Blue	Green	Red	Total
Unsmoked				
Canadian	14.0	17.5	31.4	62.9
Danish	15.6	20.2	34.7	70.3
Smoked				
Canadian	15.7	19.7	34.7	70.1
Danish	16.8	22.5	36.2	74.5

Colour Stability

The analysis of variance given in Table III shows that the only significant differences in colour stability lie between the repetitions of the experiment (i.e., between days 1 to 10 and days 11 to 19), or the average difference between sides from the same factory. The values only attain significance for blue and green in unsmoked bacon and for green in smoked bacon. This suggests that colour stability is a function of the individual side, although this cannot be stated with certainty.

TABLE III

COLOUR STABILITY OF DANISH AND CANADIAN BACONS

ANALYSIS OF VARIANCE

Variance due to:	D.f.	Mean square			
		Blue	Green	Red	Total
Unsmoked					
Between countries	1	0.02	1.26	17.3	9.08
Between factories (Can.)	9	0.97	1.48	4.63	10.5
Between factories (Dan.)	9	0.63	0.88	4.27	9.82
Between sides within factories	0 or 1	7.79**	16.8**	—	—
Error	18 or 19	0.72	0.76	8.68	13.8
Smoked					
Between countries	1	0.46	1.85	1.53	1.93
Between factories (Can.)	9	0.72	0.63	2.09	3.85
Between factories (Dan.)	9	0.55	0.98	1.95	5.31
Between sides within factories	0 or 1	—	4.52*	—	—
Error	16 or 17	0.51	0.74	2.22	7.80

* *Indicates 5% level of significance.*
** *Indicates 1% level of significance.*

TABLE IV

COLOUR STABILITY OF DANISH AND CANADIAN BACONS

Country	Change in scatter, %				
	Test	Blue	Green	Red	Total
Unsmoked					
Canadian	1 – 10	0.56	0.02	2.70	3.40
	11 – 19	−0.33	−1.21	3.64	1.94
Danish	1 – 10	0.53	0.49	1.71	2.73
	11 – 19	−0.39	−0.77	1.92	0.76
Smoked					
Canadian	1 – 10	−0.26	−0.86	1.24	0.35
	11 – 19	0.58	−0.97	1.16	0.91
Danish	1 – 10	0.12	0.14	0.67	0.93
	11 – 19	−0.53	−1.02	0.90	−0.65

Table IV shows the mean change in colour for Danish and Canadian bacons for both test periods and both classes of bacon. The consistently larger increases or smaller decreases for the samples tested on days 11 to 19 as compared with the changes during days 1 to 10 might suggest that the storage conditions during the two test periods were somewhat different. If this were true the significant differences noted between sides within factories might not present a true picture. Experimental conditions were not, however, appreciably or consistently different during the two test periods. In any case, there is little evidence that Canadian bacon is inferior to Danish in colour stability.

Relations between Subjective and Objective Observations

Owing to certain omissions, the results of the subjective observations on colour consisted of 438 comments on unsmoked material and 430 comments on smoked material. These comments were divided into six classes, viz.: good, pale, dark, fair, poor, and miscellaneous, the last class including all comments that could not be placed in the first five.

To relate the subjective observations to the four independent objective colour measurements without making arbitrary assumptions, the following procedure was adopted.

The range of objective values for, say, blue was divided into five classes. A given sample could now be placed in a given objective class and the comments of different judges on that sample distributed among the subjective categories. In this way the 38 objective measurements on smoked bacon were divided into five classes, each of which included six subjective categories.

This procedure was then repeated for the green and red measurements. Naturally, there were the same number and distribution of comments in each subjective category, but the objective measurements to which these were to be related were different for each colour. It was hoped, therefore, that this procedure might make it possible to determine the objective measurement in best agreement with the judges' comments.

This procedure reduced the results to the form of frequency diagrams (Fig. 1) having numerical values for each class capable of statistical treatment. To provide a test of significance, the subjective and objective totals for each objective class were computed. From these totals it was possible to compute the number to be expected in each subjective class, i.e., good, pale, etc., if the judges had no discriminating power and merely placed the samples in the various objective classes within subjective categories in accordance with the distribution of the totals over all the objective classes.

Having thus obtained "Observed" and "Expected" values in each row and column, it was possible by means of the Chi square test to determine whether or not the "Observed" value differed significantly from the "Expected" value. The values obtained for Chi square are given in Table V and are significant in all cases. This shows that the judges were, on the average,

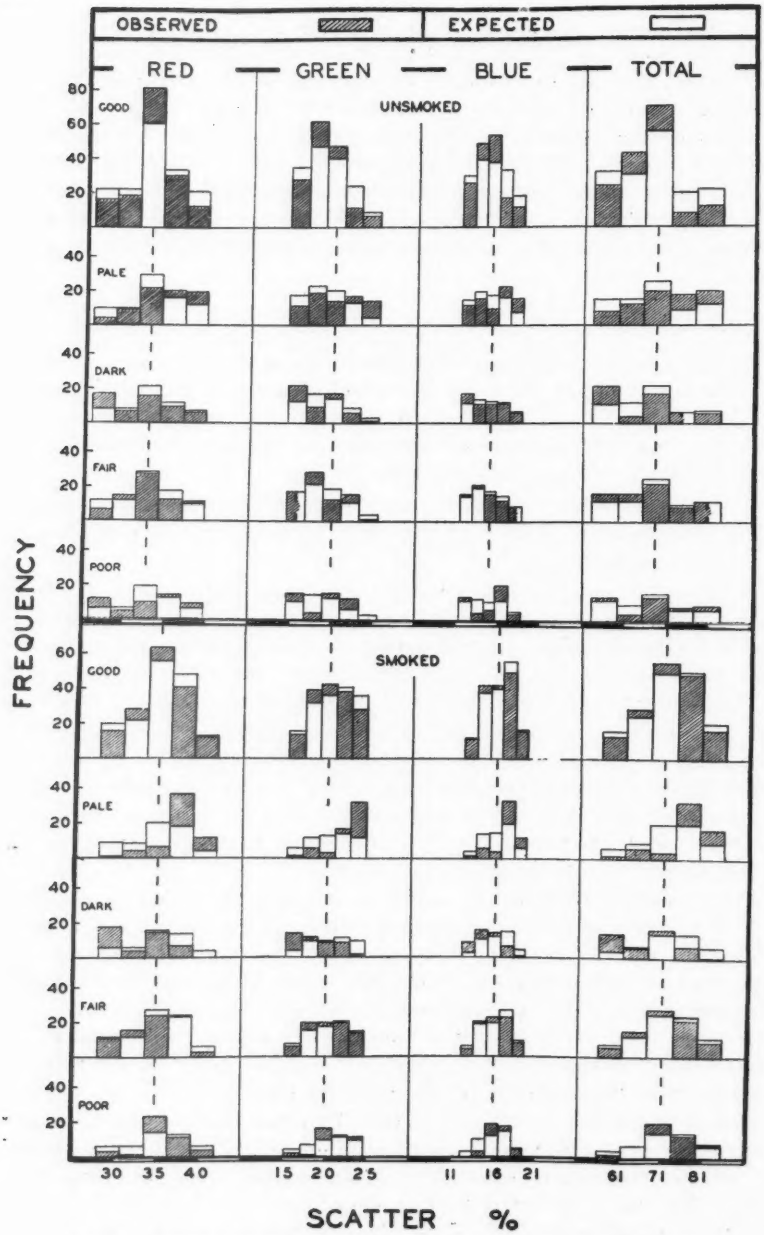

FIG. 1. *Frequency diagrams relating subjective and objective estimates of colour.*

capable of discriminating between the different colour classes adduced from the instrumental readings.

This method of analysis tests the significance of the differences for the block of data as a whole, and more detailed information must be secured from examinations of the original results and computed values.

TABLE V

VALUES OF CHI SQUARE OBTAINED IN TEST OF SIGNIFICANCE OF DIFFERENCES OF FREQUENCY OF SUBJECTIVE OBSERVATIONS FOR EACH OBJECTIVE COLOUR CLASS

Type of bacon	Objective colour class			
	Blue	Green	Red	Total
Unsmoked	67.5**	86.4**	56.9**	68.9**
Smoked	76.4**	94.6**	104.0**	85.0**

NOTE: *Value of Chi square required for 1% level of significance with 20 degrees of freedom = 37.6.*

** *Indicates 1% level of significance.*

The essential information arising from such an examination has been represented in Fig. 1. It shows the "Observed" and "Expected" values from which the reader can gain some idea of the magnitude of the difference between the two values for each independent class he may wish to compare. The frequency for both of these classes is measured from the base line so that the higher value is evident from examination. Since the red, green, blue, and total colour scatters were somewhat lower for the unsmoked than for the smoked product, the difference between them is shown in the correct relation by plotting the results from both types of bacon on the same abscissa scale.

Although Table V shows that the differences between the "Observed" and the "Expected" values are significant over all subjective observations in a given colour band, no test of significance is available for the individual objective colour class in each subjective category. Where the "Observed" value exceeds the "Expected" by a reasonable margin, however, it may be concluded that these classes contributed to the observed differences and that these objective classes are typical of the category in which they were placed by the judges.

Referring to the measurement of red in the unsmoked bacon, in the central class the number of comments in the "Good" category is in excess of the average expectation, whereas in the two end classes it is below expectation. This indicates that bacon having red scatters in the central range, i.e., 31 to 34, is most likely to be considered "Good". This conclusion is supported by the fact that the "Observed" exceeded the "Expected" in the two highest classes in the "Pale" category, indicating that samples having these red scatters, i.e., 34 to 40, are most likely to be considered "Pale". The results

are not so definite for the "Dark" class but generally speaking, samples between 25 and 30 would be considered "Dark". Since samples classified as "Fair" or "Poor" may be either "Pale" or "Dark", no definite conclusion can be drawn from these categories, but these histograms are included; those for the "Miscellaneous" have been omitted. It should be noted, however, that the "Expected" values were, in all cases, computed from the total observations over all categories, including those in the "Fair", "Poor", and "Miscellaneous" groups. Doubtless the values of Chi square in Table V would have been even larger if these classes had been excluded, but since the values are already overwhelmingly significant, no advantage would have been gained from such a procedure.

TABLE VI

REFLECTIVITY OF BACONS JUDGED TO HAVE "GOOD" COLOUR

Sample	Colour scatter in terms of white standard, %			
	Red	Green	Blue	Total
Unsmoked	31 – 34	16 – 21	13 – 16	58 – 71
Smoked	30 – 36	17 – 21	13 – 17	61 – 74
Most probable desired values	30 – 36	16 – 21	13 – 17	58 – 74

By an extension of the analyses indicated above, for all colours, for both unsmoked and smoked bacon, the values listed in Table VI are obtained as the most likely reflectivity of samples judged to have "Good" colour. Naturally, the decisions reached as to the best colour are, to some extent, arbitrary, but they do provide a working basis for future investigations.

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CANADIAN WILTSHIRE BACON

XXII. COMPARATIVE CARCASS QUALITY OF CANADIAN AND DANISH BACONS[1]

By C. A. Winkler[2], W. Harold White[3], and G. Abel[4]

Abstract

The opinions of expert judges indicated that Canadian and Danish bacon carcasses, as received on the English market, were, in general, of approximately the same quality. The eye of lean of Canadian sides was on the average slightly longer, but of approximately the same width as that of Danish carcasses. In the Canadian product the variations in the size of the eye of lean appeared to be a property of the individual side, whereas the Danish sides showed significant variations between factories.

Computations of the degree of interrelation of the measured properties demonstrated that good quality in a bacon carcass varied directly with the size of the eye of lean, and indirectly with the fat content. An increase in the content of fat was associated with a decrease in the size of the eye of lean.

Introduction

It has been shown in previous papers that definite differences in flavour quality (8) and in a number of physical and chemical properties existed between Canadian and Danish Wiltshire bacons (6, 7). It was also found that certain of the properties studied, such as the content of curing salts and quality of the fat, were related to the over-all flavour quality of the bacon side (6). However, it is evident that, irrespective of the suitability of the procedure employed for the conversion of pork to bacon, the quality of the final product is to a large extent dependent on that of the original hog carcass.

The carcass characters of the best commercial Danish bacon pig and the best breeding stock in English Large White breed have been compared by McMeekan (2). The purpose of the present paper is to present certain observations made on the comparative carcass quality of commercial Canadian and Danish Wiltshire bacon sides.

Material and Methods

The samples studied in this investigation consisted of sections of the side, approximately 2 to 3 in. in thickness, removed immediately behind the ribs and extending through the prime back. Such samples were obtained for nine sides picked at random from each of 18 Canadian and 10 Danish factories

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exporting Wiltshire bacon to England. After the grading and measurement of the eye of lean, the samples were frozen and shipped to the National Research Laboratories, as described previously, where the proportion of the fat was determined (6).

Each of the samples was graded by a committee consisting of three men of long experience in the Wiltshire bacon trade. As a result of a general inspection of the samples they considered that four definite classes could be distinguished, to one of which each sample was subsequently allocated. In addition to conformation, such factors as poor singeing and butchering and softness of the fat were considered.

Physical measurements of the eye of lean (longissimus dorsi muscle) have been used by many investigators as an index of carcass quality (1, 2, 3, 5). An approximate measure of the cross sectional area of this muscle was obtained here as the product of its maximum length and width (5).

It was also of importance to determine the proportion of physically separable fat present in the samples. The fat was carefully removed with a knife, and was then weighed.

Results

Statistical methods were employed to reduce and interpret the data (4). The relative importance of the sources of variations was determined by means of an analysis of variance. Possible sources considered here include differences between carcasses from the same factory and differences between carcasses from different factories in either Denmark or Canada, and the over-all difference between countries. Differences noted here for within factories may be considered to represent variations in carcasses from a local district or

TABLE I

CLASS OF CANADIAN AND DANISH WILTSHIRE BACON SIDES

Statistic	Country	
	Canada	Denmark
Mean	2.33	2.21
Standard deviation	0.93	0.74
Coefficient of variability	40.0	33.3

Analysis of variance

Variance attributable to:	D.f.	Mean square
Between Canadian factories	17	1.30
Within Canadian factories	138	0.816
Between Danish factories	9	0.856
Within Danish factories	66	0.499
Between countries	1	0.770
Within countries	230	0.762

variations in uniformity of grading within the individual factories. Differences between factories may be due to variations in carcasses over a wider area, or to differences in grading in the various factories. The degree of interrelation of the properties studied was estimated by the calculation of simple coefficients of correlation, and in certain instances by means of an analysis of variance and correlation ratios.

Although the mean class assigned to both Danish and Canadian Wiltshire bacon sides was approximately two, Canadian sides were of a slightly poorer grade and more variable in nature (Table I). There was some indication that variations in grading standards existed between factories both in Denmark and Canada, but such differences failed to reach the level of statistical significance. The differences between countries were likewise not significant. While the class of side commercially employed for conversion to Wiltshire bacon was better for Denmark than for Canada, there is some indication that Canadian Wiltshire sides are of a satisfactory quality.

Since it is apparent that the product of the length and width gives only an approximate estimation of the area of the eye of lean, the statistical computations were made for each of the measurements. The results of the analyses of variance, together with the mean values are shown in Table II.

TABLE II

LENGTH, WIDTH, AND AREA OF THE EYE OF LEAN OF CANADIAN AND DANISH WILTSHIRE BACON SIDES

Statistic	Measurement of the eye of lean					
	Length, cm.		Width, cm.		Area, sq. cm.	
	Canada	Denmark	Canada	Denmark	Canada	Denmark
Mean	9.08	8.90	2.82	2.84	25.7	25.4
Standard deviation	0.78	0.62	0.42	0.45	4.93	4.85
Coefficient of variability	8.59	6.96	14.7	15.8	19.2	19.1

Analysis of variance

Variance attributable to:	Measurement of the eye of lean					
	Length		Width		Area	
	D.f.	Mean square	D.f.	Mean square	D.f.	Mean square
Between Canadian factories	17	0.496	17	0.252	17	26.3
Within Canadian factories	134	0.623	134	0.162	134	24.1
Between Danish factories	9	0.618	9	0.644**	9	74.5**
Within Danish factories	59	0.348	59	0.133	59	15.7
Between countries	1	1.44	1	0.016	1	5.03
Within countries	219	0.539	219	0.181	219	24.1

** *Indicates 1% level of significance.*

The eye of lean of Canadian Wiltshire sides was on the average slightly longer, but of approximately the same width as those of Danish bacon sides. The results obtained here for commercial Danish sides were slightly greater for the length and less for the width of the eye of lean than those reported previously for the best Danish commercial product and English breeding stock in the Large White breed (2).

From the analysis of variance it may be seen that, for any of the three measurements, the average differences between sides from different Canadian factories did not exceed those attributable to sides within these factories. However, variations between the width and area of the eye of lean of the product from Danish factories significantly exceeded the differences within factories. Moreover, the variability between Danish factories in the width and area of the eye of lean was significantly greater than that between Canadian factories. In no instance, did the over-all difference between countries exceed that within countries. While the most important differences in the properties of the eye of lean for Canadian bacon occurred between sides, the major source of variance for Danish bacon was between factories.

TABLE III

INTERRELATION OF CLASS AND MEASUREMENTS OF THE EYE OF LEAN OF CANADIAN AND DANISH WILTSHIRE BACON SIDES

Class	Length, cm.		Width, cm.		Area, sq. cm.	
	Mean	Necessary difference[1]	Mean	Necessary difference	Mean	Necessary difference
1	9.54	0.345	3.15	0.19	30.2	2.13
2	9.00	0.313	2.89	0.17	26.1	1.93
3	8.81	0.461	2.62	0.26	23.0	2.84
4	8.76		2.51		22.1	

Analysis of variance

Variance attributable to:	Length		Width		Area	
	D.f.	Mean square	D.f.	Mean square	D.f.	Mean square
Between classes	3	4.85**	3	3.05**	3	496**
Within classes	217	0.460	218	0.140	217	17.5
Correlation ratio of class with:	0.357**		0.480**		0.531**	

[1] *Necessary difference between adjacent classes for 5% level of significance.*

** *Indicates 1% level of significance.*

The results of the determinations on fat content have been discussed in a previous paper (6). In brief, it was found that sides from both countries had an approximate fat to lean ratio of 60 : 40. There was some indication that differences between factories were most important for Canadian Wiltshire bacon, whereas in Denmark the prime factor was variations between sides.

Having assessed the significance of the possible sources of variation for the properties studied here, it was of importance to ascertain the extent to which these were interrelated independent of country of origin. The relation of class to length, width, and area of the eye of lean was determined by means of an analysis of variance, which is presented, together with class means, in Table III. Since the differences between classes of sides significantly exceeded those within classes for all measurements of the eye of lean, any one of the three measurements of the eye of lean is related to the over-all quality of Wiltshire bacon sides. A quantitative estimate of the interrelation, obtained by the computation of correlation ratios for each of the properties, indicated that the area, as determined here, was most closely related to the class of side.

While the over-all differences between classes were highly significant, those between adjacent grades were significant only for the first three classes. This would suggest that on the basis of the eye of lean, the judges were able to distinguish only three classes. Such factors as poor butchering, excessive singeing, poor quality of the fat, etc., may possibly have been responsible for the assignment of a side to the fourth grade.

The results of an analysis of variance for differences in fat content with class of Wiltshire bacon side showed that the over-all variations between classes exceeded those within classes (Table IV). However, when the mean fat content was considered by classes, the differences between adjacent classes

TABLE IV

INTERRELATION OF CLASS AND CONTENT OF FAT OF CANADIAN AND DANISH WILTSHIRE BACON SIDES

Statistic	Class			
	1	2	3	4
Mean	56.1	57.4	61.9	63.6
Necessary difference[1]	5.5	4.6	5.8	

Analysis of variance

Variance attributable to:	D.f.	Mean square
Between classes	3	178**
Within classes	63	29.4
Correlation ratio of class with fat content	0.473**	

[1] *Necessary difference between adjacent classes for 5% level of significance.*
** *Indicates 1% level of significance.*

failed to reach the level of statistical significance. The significant correlation ratio between class and fat content showed that poor quality in the side was associated with a high content of fat.

Simple coefficients of correlation between the content of fat and the measurements of the eye of lean were in each instance negative, and reached the level of statistical significance for the width and area (Table V). This suggests that an increase in the content of fat was associated with a decrease in the size of the eye of lean.

TABLE V

SIMPLE COEFFICIENTS OF CORRELATION BETWEEN THE OBSERVED PROPERTIES OF CANADIAN AND DANISH WILTSHIRE BACON SIDES

Quantities correlated	D.f.	r
Content of fat with:		
Class	65	.46**
Length of eye of lean	63	− .22
Width of eye of lean	63	− .54**
Area of eye of lean	63	− .52**
Class with flavour score:		
Importers' jury group	26	.07
Smithfield jury group	26	− .19
Family group test	26	− .17
Area of eye of lean with flavour score:		
Importers' jury group	26	.07
Smithfield jury group	26	− .08
Family group test	26	− .10

** *Indicates 1% level of significance.*

It was of interest to determine the extent of correlation between the subjective estimates of eating quality, as provided by the jury groups and family group flavour tests (8), and those of carcass quality of the Wiltshire bacon side. The correlations between class and area of the eye of lean and flavour score were for the most part negative, but not statistically significant. However, since the majority of these were negative, there is some indication that quality in the Wiltshire carcass is reflected in the eating quality of the bacon.

Discussion

From the results presented here it would appear that the average Canadian Wiltshire side compares favourably with that of Denmark.

In addition to grading, the judging committee commented on excess singeing of the bacon sides. Of the Canadian and Danish sides, 14 and 23%, respectively, were criticized for defective singeing. Canadian factories would appear to be definitely superior with respect to precautionary measures taken to minimize scorching of the sides. Complaints of scorching of the Canadian product, however, were made against seven sides treated in vertical types

of singers, nine in the Danish "clam-shell" type, and two prepared by each of the hand, open, and horizontal methods. The proportions of complaints, when considered with respect to factories, were approximately the same for all the types of singeing commonly employed in Canadian practice.

Acknowledgments

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THE CULTIVATION OF TAPEWORMS IN ARTIFICIAL MEDIA[1]

By Nancy Katharine Green[2] and Robert Arnold Wardle[3]

Abstract

Experiments were made with the tapeworms *Diphyllobothrium latum* (L.), *Moniezia expansa* (Rud.), and *Hymenolepis fraterna* (Stiles), to free them from adherent bacteria and keep them physiologically active in artificial media. Surface sterilization was attained by five minutes exposure to a 10% saline solution of silver protein (Merck), or by the sedimentation method of washing in saline. No success was obtained with bacteriological media but in a dilution of Baker's tissue culture medium *A* (10 drops to 5 cc. of Tyrode's solution), *Hymenolepis fraterna* remained active for 20 days, considerably exceeding its normal longevity *in vivo*.

1. Introduction

The technique of keeping intestinal worms alive and physiologically active when outside their normal hosts is rudimentary, and with tapeworms the results obtained have been disappointing owing to their extreme fragility, their extreme restriction of habitat, and their susceptibility to bacterial attack. The problem is made particularly difficult by the absence of information concerning their alimentary and respiratory processes.

The problem is to establish a non-lethal method of freeing the tapeworm surface from adherent bacteria, after removal from the host, and to establish a nutrient medium in which the tapeworm will remain physiologically active for a period at least as long as the normal life period spent within the host.

For a summary of the results so far obtained, reference may be made to Wardle (8, 9, 10, 11). It may be said, briefly, that greater success has been obtained with larval tapeworms than with adults, but in no case has true growth been observed, and the success of such experiments has to be estimated by the length of time that the worms remain actively undulant. The maximum values so recorded fall considerably short of the length of life within the host environment where this latter value is known.

2. Tapeworm Sterilization

Two methods of sterilizing the tapeworm surface are available: (1) exposure to saline dilutions of bactericidal substances; (2) washing with sterile saline solutions, either by simple rinsing or by *sedimentation*, that is to say, by allowing the worm to fall repeatedly through columns of sterile saline so that the lighter bacteria are left suspended in the upper layers of the solution. Few observations have been recorded as to the effect of bactericides upon tapeworm viability. Coutelen (4) has noted the lethal effect of mercuric chloride (1 : 1000) and formalin (1 : 200) upon larval *Echinococcus*; Clapham (1),

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the lethality of hexyl resorcinol in dilutions of 1 : 1000 to 1 : 20,000 upon *Hymenolepis fraterna* (Stiles); Wardle (9), the adverse effect of a wide range of common bactericides upon the longevity of larval *Nybelinia surmenicola* Okada.

In the present experiments tests were made with a number of organometallic bactericides recommended for sterilizing mucous membranes; in addition, tests were made with resorcinol, phenol, trikresol, and chloramine *T*. These substances were dissolved in physiological saline (Tyrode's solution) in percentage proportions of 0.0001, 0.001, 0.01, 0.1, and 1.0. They were tested upon the common sheep tapeworm, *Moniezia expansa* (Rud.). The scolex and neck region were snipped from each adult worm (as soon as possible after removal from the sheep), rinsed with warm sterile saline solution, then transferred (to test the effect on the worm) to sterile Tyrode's solution, or transferred (to test the degree of bacterial inhibition) to agar plates. The worms were subsequently kept at 37.5° C.

Untreated worms, kept in Tyrode's solution, did not remain actively undulant for more than 24 hr. On agar plates they became septic within 48 hr. The maximum periods of undulant activity among the treated worms are given in Table I. At all higher concentrations of the above substances,

TABLE I

MAXIMUM PERIODS OF UNDULANT ACTIVITY OF WORMS TREATED BY VARIOUS STERILIZING SOLUTIONS AND CULTURED IN VARIOUS NUTRIENT MEDIA

Sterilizing solution	Concentration, %	Period of activity, hr.
Silver protein	0.1	168
Chloramine *T*	0.1	144
Argyrol (A. C. Barnes)	1.0	96
Chinosol (Burrows Wellcome)	0.01	96
Mercurescein (Ingram and Bell)	0.1	96
Phloroglucin	0.1	72
Resorcinol	0.01	48
Trikresol (Schering)	0.01	48
Phenol	0.01	48
Neosilvol (Parke Davis)	0.1	24
Nutrient media		
Tyrode's solution		168
Nutrient agar and hog serum		120
Hog serum		48
Nutrient agar (saline)		48
Heart infusion broth (aqueous)		48
Nutrient gelatine (aqueous)		33
Heart infusion broth (saline)		24
Gastric mucin		12
Dextrose broth (aqueous)		9
Tryptose phosphate		Lethal (immediately)
Kracke's blood culture medium		Lethal (immediately)

and in *all* concentrations of merthiolate (Eli Lilly and Co.), the worms died immediately. After exposure to the relatively non-lethal dilutions, complete bacterial freedom seemed to have been conferred (to judge by the subsequent absence of bacterial contamination of the agar plates) by silver protein, mercurescein, chloramine *T*, argyrol, and phloroglucin. Bacterial contamination, after 24 hr., appeared in plates containing those worms that had been exposed to neosilvol, resorcinol, phenol, and trikresol.

The bacterifugal effect of simple rinsing with sterile saline solution was tested upon larval *Diphyllobothrium latum* (L.), separated from adherent fish muscle by soaking overnight in Tyrode's solution at 37.5° C. After rinsing with sterile saline, the worms were removed in batches of 10 to common bacteriological media (see Section 3). No subsequent bacterial contamination of the media was observed within 48 hr., but as the maximum periods of undulant activity did not, with one exception, exceed 48 hr., the experiments must be regarded as inconclusive. In Tyrode's solution alone, worms rinsed in such a manner lived 168 hr. without perceptible sepsis.

The sedimentation method of obtaining freedom from bacteria—used with success by Cleveland (3) for protozoa, Ferguson (5) for trematode cercariae, and Glaser and Stoll (6) for nematode worms—was tested upon specimens of *Hymenolepis nana* var. *fraterna* (Stiles). This is a small worm common in wild rats and peculiar in being able to carry out its whole life cycle within the host; rats can be infected by being fed eggs or whole tapeworms, and, despite the short life period within the host, a strain of tapeworms can be maintained indefinitely in laboratory animals. The small size of this worm (less than 50 mm.), its availability in rats throughout the year, and its marked undulant activity, make it a most suitable subject for experiments of this nature. After removal from the host, the hymenolepids were washed by being allowed to fall 10 times in succession through columns of sterile Tyrode's solution. Four-inch test tubes were used, the supernatant fluid being poured off before the worms were removed from the bottom of the tube and transferred to a fresh tube. Final transference was made to sterile media in small Petri dishes. In sterile Tyrode's solution, the worms, after sedimentation, remained active up to nine days. In Baker's Medium *A*, some remained sterile and active up to seven days, but some became septic within 24 hr. In the very dilute medium finally adopted (see Section 3), they remained sterile up to 20 days, the maximum period of undulant activity recorded.

3. Nutrient Media

In the absence of information as to their food requirements, attempts to feed tapeworms *in vitro* cannot be other than empirical. Wardle (9) describing experimental cultivation of larval tapeworms on a range of saline and semi-

solid media, suggests that from the standpoint of retention of normal appearance and of movement, rather than duration of undulant activity, nutrient gels under aseptic conditions offer the best possibilities for tapeworm cultivation.

In the present experiments the nutrient media tested were liquid and comprised a series of Difco bacteriological media and the tissue culture medium known as Baker *A* (2).

In one series of experiments, plerocercoid larvae of *Diphyllobothrium latum*, after being rinsed with sterile saline, were transferred to a range of nutrient broths made up according to the manufacturers' directions, in water or saline, and sterilized by Seitz filtration. The cultures were incubated at 37.5° C. The maximum periods of undulant activity recorded are shown in Table I. One specimen in nutrient agar plus hog serum grew to a length of 50 mm., which is three times the maximum length recorded among 100 measured plerocercoids.

In a second series of experiments, hymenolepid worms, after sedimentation, were transferred to dilutions of the tissue culture medium, Baker *A*, which is essentially a solution of Witte's peptone (0.675%) in a balanced saline solution containing small quantities of cysteine hydrochloride, hemin, insulin, thyroxine, glucose, vitamin A, ascorbic acid, and glutathione; immediately before use, 10% of ox serum was added.

In Tyrode's solution alone the worms remained active up to nine days; in Baker's medium alone, they remained active up to seven days, but the medium showed bacterial clouding and had to be renewed every two days. In mixtures of Baker's and Tyrode's in proportions 1 : 3, 2 : 2, 3 : 1 they remained active up to three days. The most satisfactory combination was found to be a very dilute solution of Baker's medium in Tyrode's solution, 10 drops of Baker's to 5 cc. of Tyrode's. In this medium, undulant activity without bacterial clouding was maintained for as long as 20 days.

4. Conclusions

Although the average length of life of *Hymenolepis fraterna* in the rat is not known with certainty, there is a general belief among students of the question that the postmaturation period of the life cycle is brief. Shorb (7) gives an average value of 11 to 16 days for the prematuration phase of the life cycle, 11 days for the postmaturation phase.

Maintenance of mature *Hymenolepis fraterna* in an artificial medium for as long as 20 days must be regarded therefore as a satisfactory test of the suitability of the medium selected and of the preliminary treatment for freeing the worm from adherent bacteria.

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THE RATE OF GROWTH OF THE TAPEWORM *DIPHYLLOBOTHRIUM LATUM* (L.)[1]

By Robert Arnold Wardle[2] and Nancy Katharine Green[3]

Abstract

Observations on scolex length, total weight, total length, and weight–length ratio, of specimens of *Diphyllobothrium latum* (L.), reared in dogs, suggest that the increase in scolex length as the worm ages is due to deterioration of the scolex musculature; that increases in weight and length during the first six days within the host are due to water absorption; that from the sixth day to the 15th day, growth is rapid and may be expressed by the formulae:—

$$W \text{ (weight)} = (0.18)e^{0.61n},\ L \text{ (length)} = (2.3)e^{0.39n},$$
$$\text{and } W/L \text{ (weight–length ratio)} = (0.08)e^{0.22n}$$

where e is the natural logarithm base and n is the age in days. After the 15th day, the values of W/L fluctuate rhythmically, the high values corresponding to periods of strobila apolysis, the low values corresponding to periods of egg discharge. Examination of a wide range of specimens from man and dog suggests that, with exceptions, the average weight–length ratio fluctuates between values of 3.0 and 5.0 in mature egg producing specimens.

1. Introduction

Information concerning the rate of growth of tapeworms is scanty. They cannot be continuously observed whilst within their hosts. They cannot be kept alive for more than a few days outside such hosts. The rate of growth must, therefore, be inferred by measuring groups of individuals of known ages, and the study of tapeworm growth is limited to such tapeworm species as can be reared in laboratory animals or in man. The only published observations on tapeworm growth are those of Petruschewsky and Tarassow (3, 4) on *Diphyllobothrium latum* (L.), of Penfold, Penfold, and Phillips (2) on *Taenia saginata* Goeze, and of Chandler (1) on *Hymenolepis diminuta* (Rud.).

The choice of a criterion of growth changes in tapeworms is restricted by the absence, in these animals, of exoskeleton, endoskeleton, and osmotic rigidity. The living worm rhythmically contracts and expands; it is freely permeable to water so that weight and length are affected by the nature of the medium in which it is examined or preserved; commonly, only a fragment of a tapeworm may be available for examination.

Linear length, used as a criterion of growth by previous authors, whilst applicable to small tapeworms such as hymenolepid species or plerocercoid larvae, is less applicable to large tapeworms and not applicable at all to fragments; a similar objection may be raised against the value of *total weight*.

The value of *average cross sectional area*, calculated from average length, average weight, and average specific gravity, offers the advantage of applic-

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ability to fragments. In the case of *Diphyllobothrium latum*, preserved in 5% aqueous formalin, the specific gravity fluctuates narrowly on either side of unity and the average cross sectional area may be regarded as equivalent to the weight–length ratio.

2. Methods

Specimens of *Diphyllobothrium latum*, obtained from fish, were reared in young dogs of similar breed, age, weight, size, and genetic origin. Each dog was infected with five plerocercoids of *Diphyllobothrium latum*, all dogs being infected at the one time with plerocercoids taken from one batch of fish. The dogs were killed at intervals of 3 to 30 days after initial infection and the worms were removed, killed in hot 5% formalin, preserved and afterwards measured in the same medium. From 60 plerocercoids, 39 worms were thus recovered. Measurements were made of the scolex length and of the total length of worms ranging from 3 to 75 days and 3 to 98 days of age, respectively.

Tapeworms killed and preserved in a hypotonic medium absorb water readily and the values of length and weight observed can be compared only with those observed for other worms killed and preserved in the same way. Formalin fixation offers advantages over ice water immobilization of the living worm in permitting comparison with casually collected specimens which almost invariably are fixed and preserved in weak formalin; it also permits lengthy storage of specimens with little change beyond a negligible alteration in weight due to oxidation of part of the phospholipid content.

Little advantage is gained in superinfecting dogs with large numbers of plerocercoids in the hope of gaining large numbers of adult worms. Such superinfected hosts tend to lose the majority of their parasites. Among dogs superinfected with 30 to 50 plerocercoids, the majority lost their worms completely after the 25th day; the greatest number recovered from any one dog was 27, after 75 days' infection. One dog initially infected with 30 plerocercoids had only eight worms at the end of 98 days. It may be noted, that a low number of tapeworms per individual has also been recorded by Petruschewsky and Tarassow (3) in a northern Russian population exposed to superinfection with *Diphyllobothrium latum*. Moreover, the length values of worms from superinfected dogs contrast unfavourably with those of worms from lightly infected animals. Chandler (1) found that the average length of *Hymenolepis diminuta* in laboratory rats is in inverse proportion to the number of worms present, ranging from an average of 1000 mm. in single-worm infections to 300 mm. in 40-worm infections.

3. Discussion of Data

In Table I are given average scolex lengths of larval specimens of known ages, killed in hot 5% formalin. The data suggest a progressive increase in length as the worm grows older. Among plerocercoids whose scolices have been everted by immersing the worms in physiological saline, the scolices are

TABLE I

AVERAGE SCOLEX LENGTHS OF *Diphyllobothrium latum* (L.) OF KNOWN AGES

Age, days	Number	Range of lengths, mm.	Average length, mm.
3	7	0.368 – 0.828	0.526
6	5	0.736 – 0.828	0.797
9	5	0.644 – 0.736	0.690
12	3	0.736 – 0.920	0.797
15	3	0.736 – 0.828	0.770
18	2	0.828 – 1.104	0.966
21	3	0.736 – 1.104	0.889
24	7	0.736 – 1.288	0.999
27	2	0.920 – 1.192	1.104
30	3	0.937 – 1.945	1.104
56	24	1.020 – 2.400	1.523
75	29	1.125 – 2.400	1.700

extremely mobile, expanding to a length of 1.5 to 2.0 mm. by muscular contraction, then contracting through muscular relaxation to a length of only half that value. When killed in hot formalin, the scolex remains digitate or lanceolate in shape and at its minimum value of length. As the worm grows older, such mobility is less marked, owing apparently to a degeneration of the scolex musculature. The scolex when expanded is never so long, when contracted never so short, as is the newly everted one. In an old worm, the range between expanded and contracted length diminishes until the scolex seems almost immobile, and living or dead, remains club-shaped, spoon-shaped, or almond-shaped. The effect is thus one of increasing scolex length as the worm grows older.

The function of the scolex is to anchor the early strobila to the host gut wall. In the older worm, maintenance of position in the host gut is effected by muscular tonus, by pressure of the powerfully muscular strobila against the gut wall; the scolex serves little purpose, adheres only loosely to the gut wall, and any increase in its size and development is not to be expected.

Table II presents the data obtained for weight and length and weight–length ratio of entire worms, in each age group. Between the maximum and minimum values of weight and length, there is in each age group a relatively wide spread, and it does not seem possible to determine the possible age of a fragment of *Diphyllobothrium latum* by inspection of the weight–length ratio. Such variation in weight and length within each age group arises in part from the corresponding variation of the plerocercoids used for initial infection.

The lengths of 56 plerocercoids, killed, preserved, and measured in 5% formalin, ranged from 1.0 to 17.5 mm.; 41 of these had lengths between 1.5 and 6.5 mm., the average length being 3.7 mm. Fifty plerocercoids ranged in weight between 0.1 and 7.16 mg.; 36 of them had weights between 0.3 and 2.0 mg., the average weight being 1.4 mg. The W/L value of 0.4 is thus much higher for the plerocercoid than for the worms between one and

TABLE II

AVERAGE WEIGHT, LENGTH, AND WEIGHT/LENGTH VALUES FOR *Diphyllobothrium latum* (L.) REARED IN DOGS, AND KILLED AND PRESERVED IN 5% FORMALIN

Age, days	Number	Average weight, mg.	Average length, mm.	Weight/length ratio
		5 plerocercoid infections		
3	7	1.44	7.09	0.203
6	5	5.30	20.20	0.262
9	5	43.20	81.20	0.532
12	3	276.30	250.25	1.103
15	4	2350.00	659.00	3.57
18	3	3890.00	698.00	5.57
21	4	2660.00	664.00	4.01
24	3	1676.00	266.20	6.30
27	2	2215.00	660.00	3.36
30	3	9215.00	1436.00	6.42
		30 to 50 plerocercoid infections		
32	4		256.00	
41	4		1250.00	
50	1		765.00	
56	24		385.00	
65	10		360.00	
75	27	1850.00	558.00	3.32
98	8		1688.00	

six days old. If, however, the relatively high specific gravity, of 1.38, of the plerocercoid stage be taken into consideration, W/L becomes 0.274 which compares closely with that of the one-day to six-day worms. It is possible, therefore, that no true growth of the young worm, in the sense of new tissue formation, occurs within the first six days, but that the apparent increase in weight and length is due to water absorption. It may be noted that Chandler (1) found very slow linear growth in *Hymenolepis diminuta* during the five-day to seven-day period in the host, as compared with the rapid growth during the 7- to 18-day period. The average length value of 20 mm. (given in Table II) for the six-day old worms may be contrasted with the value of 27.0 mm. found by Petruschewsky and Tarassow (4) for *Diphyllobothrium latum* (L.) of the same age in a dog.

Without further knowledge of the food requirements of *Diphyllobothrium latum* conclusions cannot be drawn as to the influence of its position in the host gut upon available food supply and upon its consequent weight and length. Among 80 worms, ranging from 3 to 98 days old, only 5% lay in the first quarter of the host gut, measured between pylorus and ileocolic valve; 37.5% lay in the second quarter; 22.5% in the third quarter; the remaining 35% in the fourth quarter. In the case of *Hymenolepis diminuta*, Chandler (1) found that the worms take up their initial position far back in

the gut and subsequently move forward. Our observations upon the position of young specimens of *Diphyllobothrium latum*, in kittens, showed that after 13 hr. from initial infection the worms lay at distances of 7, 11, 12, 13, 16 in., respectively, from the pylorus in a gut measuring 33 in. between pylorus and ileocolic valve; after 25 hr., 17 worms lay at distances between 7.5 and 36 in. from the pylorus in a gut measuring 56 in. between pylorus and ileocolic valve. These observations suggest that scattering of the individuals of an age group along the gut is as characteristic of the first few hours of infection as of the later days of infection.

The data of Table II suggest that during the period 6 to 15 days after initial infection, growth is rapid and progresses geometrically according to the general formula $G = (A)e^{kn}$ where G is the growth value, A and k are constants, e is the natural logarithm base, and n is the age in days. The

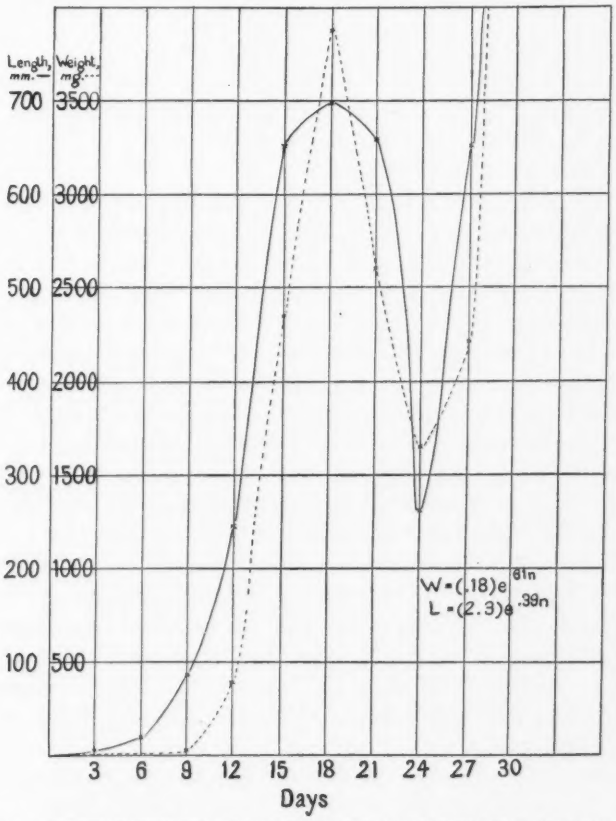

FIG. 1. *Increase in length and weight of specimens of Diphyllobothrium latum (L.) in dogs*

actual values of weight *(W)*, length *(L)*, and weight–length ratio *(W/L)* recorded fit the formulae:—

$$W = (0.18)e^{0.61n}, L = (2.3)e^{0.39n}, \text{ and } W/L = (0.08)e^{0.22n}.$$

During this 6- to 15-day period the average daily increment of length was 48 mm. During the 15- to 30-day period it was 61.5 mm. Petruschewsky and Tarassow (4) for the 6- to 36-day period, found the average daily increment of length to be 47 mm. for *Diphyllobothrium latum* in a dog, 150 mm. for a specimen in a man.

As may be seen in Fig. 1, the value of W/L reaches a peak on the 18th day after initial infection. This peak coincides with the appearance in the posterior proglottids of the first batch of eggs. In *Diphyllobothrium latum*, whether in man or dog, the first discharge of eggs occurs between the 18th and 20th day; the exhausted proglottids diminish to one-half or one-third of their former weight, eventually disintegrate, and break free from the strobila.

In Table II this first egg discharge is clearly indicated by the fall in W/L value in the 21-day specimens. The first apolysis, or shedding of exhausted tissue, is indicated by the rise in W/L value in the 24-day specimens. Subsequent egg discharges are indicated by lower W/L values; subsequent apolyses are indicated by heightened W/L values.

The conclusion may be drawn that egg discharge and tissue apolysis are not continuous phenomena, but occur, as it were, spasmodically at intervals which, up to 30 days after initial infection, appear to be of a duration of three days. The W/L values thus rise and fall between certain limits. An examination of a large number of fragments of *Diphyllobothrium latum* from man and dog, from various localities, suggests that these limits are approximately 3.0 and 5.0. Outstanding exceptions were provided by some specimens from man. One enormous specimen from Leningrad had a W/L value of 11.0 and two from Saskatchewan had values of 7.55 and 7.83, respectively. A Russian specimen, known to be 36 days old, had a W/L value of 5.70. Clearly any metabolic features of the host that stimulate egg production in *Diphyllobothrium* will produce an unusually high W/L value; those that suppress egg production whilst stimulating linear growth, will lead to an unusually low W/L value, but the nature of the metabolic features is at present unknown.

The 30-day period of the experiment was too short to indicate whether new growth exceeds or merely keeps pace with apolytic loss. Penfold, Penfold, and Phillips (2), studying *Taenia saginata*, found an increase of 9 to 12 proglottids per day, and a loss of 8 to 9 proglottids per day, growth thus exceeding apolysis.

In an apolytic tapeworm, growth during early life may be expected to exceed apolytic loss, whereas later in life it should merely equal it and later still should lag behind it.

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